AD NUMBER
ADB016502
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 30 JUN 1975. Other requests shall be referred to Office of the Assistant Secretary of Defense, Installations and Logistics, Washington, DC 20301.**
AUTHORITY
OASD ltr 29 Jul 1977

APL/JHU
SR 75-3C
JUNE 1975

DOD WEAPON SYSTEMS SOFTWARE MANAGEMENT STUDY

APPENDIX C, AIRBORNE SYSTEMS

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

Distribution of this document is limited to U.S. Government agencies because it contains Test and Evaluation Data. This study was published on 30 June 1975. Other requests for this document must be approved by [redacted], Office of the Assistant Secretary of Defense for Installations and Logistics, The Pentagon, Washington, D.C. 20301.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

PLEASE FOLD BACK IF NOT NEEDED FOR BIBLIOGRAPHIC PURPOSES

REPORT DOCUMENTATION PAGE

1. REPORT NUMBER
14 APL/JHU-SR-75-3C

2. GOVT ACCESSION NO

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 DOD WEAPON SYSTEMS SOFTWARE MANAGEMENT STUDY. APPENDIX C. AIRBORNE SYSTEMS,

5. TYPE OF REPORT & PERIOD COVERED
9 Special Report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

8. CONTRACT OR GRANT NUMBER(s)
15 N00017-72-C-4401

9. PERFORMING ORGANIZATION NAME & ADDRESS
The Johns Hopkins University Applied Physics Laboratory
Johns Hopkins Rd.
Laurel, MD 20810

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Task ZC-6

11. CONTROLLING OFFICE NAME & ADDRESS
Office of the Assistant Secretary of Defense
(Installations and Logistics), [redacted]
Pentagon, Rm. 2A318, Washington, DC 20301

12. REPORT DATE
11 June 1975

13. NUMBER OF PAGES
105

14. MONITORING AGENCY NAME & ADDRESS
Naval Plant Representative Office
Johns Hopkins Rd.
Laurel, MD 20810

12 115 p.

15. SECURITY CLASS (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

10 J. F. Bradshaw,
T. R. Foard,
P. L. Hagan,
H. Ginsberg
A. Michelsen

16. DISTRIBUTION STATEMENT (of this Report)
Distribution of this document is limited to U.S. Government agencies because it contains Test and Evaluation Data. This study was published on 30 June 1975. Other requests for this document must be approved by the controlling office (Item 11).

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Software
- Disciplined programming
- Software architecture
- Software definition
- Software deliverables
- Software design
- Software development tools
- Software implementation

(cont'd)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This appendix to the DoD Weapon Systems Software Management Study conducted by APL contains information on Airborne Systems presented in more detail than is given in the main report. The specific systems discussed are the E-2C Tactical Data System, the P-3C Airborne Patrol System, the S-3A Airborne Weapon System, and the F-14 Avionics and Weapon Delivery System. Each section is divided into a General System Description; Computer System Architecture; Computer Program Architecture; Software Definition, Design, and Implementation; Software Validation and Integration; Software Acquisition Management Organization and Methods; Operational Software Maintenance; and Highlights.

DD FORM 1 JAN 73 1473

031 650

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

APL/JHU
SR 75-3C
JUNE 1975

DOD WEAPON SYSTEMS SOFTWARE MANAGEMENT STUDY

APPENDIX C, AIRBORNE SYSTEMS

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road, Laurel, Maryland 20810
Operating under Contract N00017-72-C-4401 with the Department of the Navy

19. KEY WORDS (cont'd)

Software integration
Software maintenance
Software management
Software operational support agent

Computer Subsystems

AWG-9 Weapon Control System (F-14)
CSDC Subsystem (F-14)

Computer System Management

Provisions for growth
Requirements analysis and validation
System integration and test capability
Systems engineering
Systems engineering agent

Computers

AYK-10
CDC 5400B
CP-901/ASQ-114(V)
OL-77/ASQ (Litton L-304F)
Teledyne CP-1050

Weapon Systems

E-2C Tactical Data System
F-14 Avionics and Weapon Delivery System
P-3C Airborne Patrol System
S-3A Airborne Weapon System

ABSTRACT

This appendix to the DoD Weapon Systems Software Management Study conducted by APL contains information on Airborne Systems presented in more detail than is given in the main report. The specific systems discussed are the E-2C Tactical Data System, the P-3C Airborne Patrol System, the S-3A Airborne Weapon System, and the F-14 Avionics and Weapon Delivery System. Each section is divided into a General System Description; Computer System Architecture; Computer Program Architecture; Software Definition, Design, and Implementation; Software Validation and Integration; Software Acquisition Management Organization and Methods; Operational Software Maintenance; and Highlights.

ACKNOWLEDGMENT

The following APL staff members participated in the visits to the Airborne Weapon Systems Program Managers, Facilities, and Contractors and/or in the preparation of the reports: J. F. Bradshaw, T. R. Foard, P. L. Hazan, H. Ginsberg, A. Michelsen, L. Montanaro, J. G. Palmer, K. E. Richeson, and W. J. Sanda. The editor for this appendix was H. M. Stainer. The assistance of the Weapon Systems Program Managers and Contractors in reviewing their respective sections is gratefully acknowledged.

TABLE OF CONTENTS

CONTENTS

LIST OF ILLUSTRATICNS

INTRODUCTION

INTRODUCTION

1. INTRODUCTION

1.1 OBJECTIVES AND APPROACH

The Weapon System phase of the APL DoD Weapon Systems Software Management Study was concerned with specific applications of software design and management to major Weapon Systems. The systems were selected to represent a variety of platforms and major missions and to illustrate all phases of the Weapon System life cycle.

The survey of individual Weapon Systems, as a major input to the overall APL study, had the following objectives:

1. To serve as a basis for understanding how and what Weapon Systems software is being or has been developed, produced, deployed, and maintained in the user environment;

2. To serve as a basis for distinguishing among the large range of uses of software in Weapon Systems; differences in function, size, and complexity; and the way these differences affect software problems and potential solutions;

3. To provide insight into the organizational relationships between the Government Program Managers, system contractors, software contractors, and Government test, maintenance, and training facilities;

4. To identify design and management techniques that have proved successful and that warrant more general application; and

5. To obtain opinions from key personnel concerning ways in which the Office of the Secretary of Defense (OSD) or the Services can contribute to the improvement of software cost and performance.

The survey of Weapon Systems software was carried out through the auspices of the respective Program Managers. System and software contractors were visited, where possible, to obtain first-hand information on system characteristics and development methods.

The selected Airborne Weapon Systems are listed in Table 1-1. Two other Appendices in this study discuss Shipborne Systems and Undersea and Landbased Systems. These three Appendices present more detailed information than was given in Section 4 of the main report.

TABLE 1-1

AIRBORNE SYSTEMS INVESTIGATED

Weapon System Programs	Systems	Status
E-2C	Tactical Data System	Deployed
P-3C	Airborne Patrol System	Deployed
S-3A	Airborne Weapon System	Production/ Deployed
F-14	Avionics and Weapon Delivery System	Deployed

The individual discussions vary in detail because of the differing stages of development of the different systems. The following kinds of information were sought:

1. General System Description: A sufficient description to provide understanding of the overall system mission and requirements and the operating environment of the embedded computer system;

2. Computer System Architecture: The selection of computing equipments and their operating relationships, including the functions allocated to each computational unit;

3. Computer Program Architecture: The structure used in computer program design throughout the system, including allocation of functions to elements of the computer programs;

4. Software Definition, Design, and Implementation Methods: Techniques used in software system design management and control, especially those that have had apparent success;

5. Software Validation and Integration Methods: Management techniques, testing tools and techniques, and facilities used in software quality assurance;

6. Software Acquisition Management Organization and Methods: Methods used by the Government, system contractor, and software contractor to manage the process of software design and validation; and

7. Operational Software Maintenance: Approach used or plans for transfer of developed software to Government control for lifetime support and maintenance.

Each paragraph in the Highlights section for each Weapon System is followed by one or more designations (e.g. (SE1)) in parentheses. These designation(s) indicate the APL recommendation(s) from the main report that correlate most closely with the particular highlight.

1.2 AIRBORNE SYSTEMS

The four airborne systems selected for study represent several evolutionary lines of system development that provide the Fleet with Airborne Early Warning (AEW), Antisubmarine Warfare (ASW) capability, and fighter-interceptor capability.

The E-2C Tactical Data System evolved in early 1970 from the E-2B and was deployed in 1974. It incorporated a new radar, display system, and passive detection system. The first AEW aircraft of this series, the E-2A, employed a drum computer. The L-304F computer selected for E-2B and E-2C was the first airborne multiprocessor.

The P-3C and S-3A Airborne Systems are interrelated developments that stem from exploratory work at the Naval Air Development Center (NADC) in Warminster, Pennsylvania. These systems have automated the tasks of acoustic submarine detection and tracking, and assist in aircraft direction. Several computers have been used. The latest, the Univac 1832, is similar to the AN/UYK-7 computer used in shipboard applications.

The platform for the F-14 Avionics and Weapon Delivery System is the F-14 Tomcat, a carrier-based fighter interceptor aircraft. The AN/AWG-9 weapon control system used provides a significant increase in weapons and surveillance capability over previous interceptors. Improved data links between this aircraft and surface units provide closer coordination of surface and airborne defensive actions. Separately developed computer programs are used in the weapon control system and in the avionics system. The Weapon System development started in the early 1960's and later became part of the F-14 aircraft. The first F-14 operational squadrons deployed in 1974.

Table 1-2 lists the computers employed in these four systems. There has been less tendency to standardize computer equipments for airborne systems than for shipborne systems. Current plans for an All-Application Digital Computer (AADC) may provide a modular family of computers that will meet the constraints of airborne systems.

TABLE 1-2

AIRBORNE COMPUTERS

Computer Designation	Word Length (bits)	Cycle Time (μs)	System	No. CPU's
OL-77/ASQ (Litton L-304F)	32	2.2	E-2C	2
CP901/ASQ-114(V)	30	2	P-3C	1
AYK-10	32	1.5	S-3A	2
CDC 5400B	24	1	F-14	1
Teledyne CP-1050	20	7.5	F-14	1

Figure 1-1 represents the computer and display capacities for these airborne systems. Generally smaller than shipboard systems because of size and mission limitations, these systems have expanded memory capability, where needed, by the use of disk or drum peripheral units.

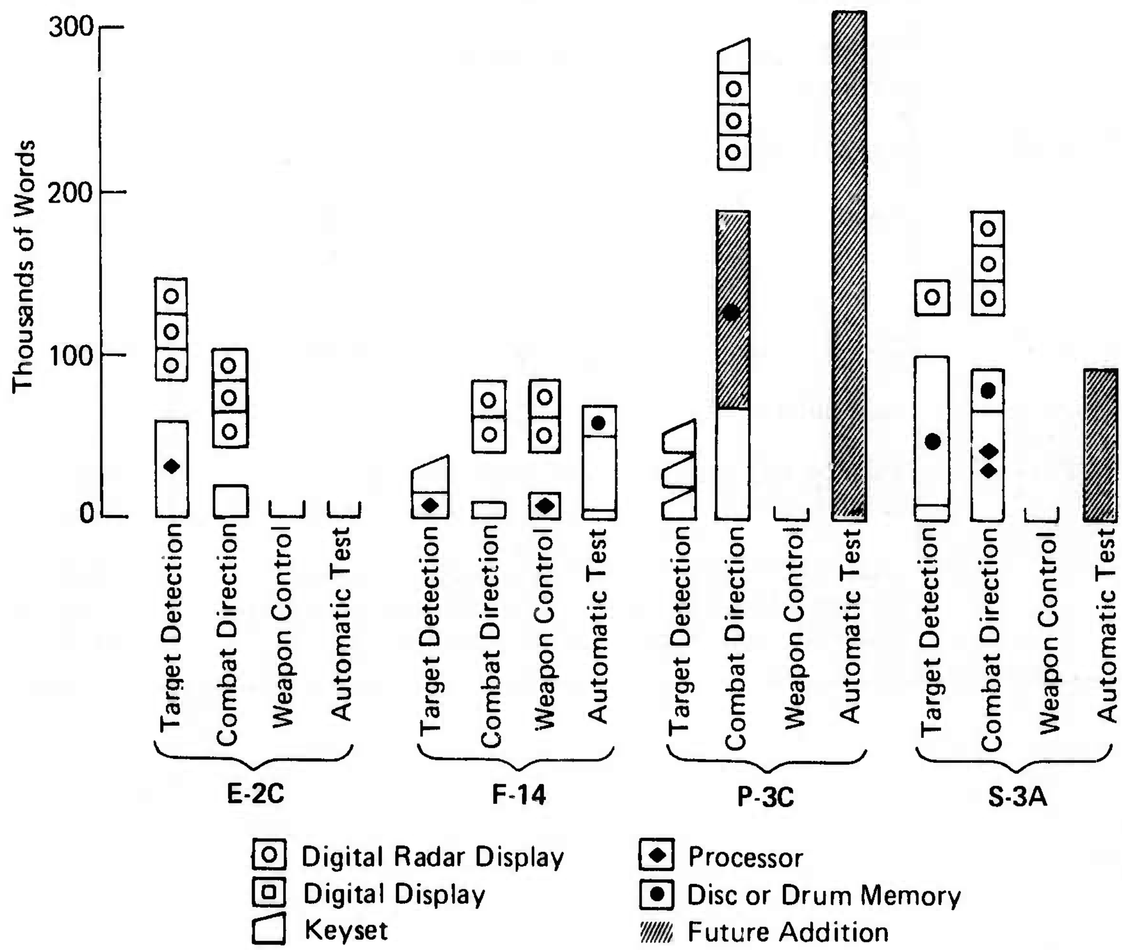


Fig. 1-1 Comparison of Airborne Systems

Table 1-3 lists visits made to Program Managers, support activities, and contractors in pursuit of information relating to these programs.

TABLE 1-3

WEAPON SYSTEM PROGRAM VISITS

Weapon System Program	Agency Visited	Responsibility	Date (1975)
E-2C	NAVAIR PMA 231A	Program Manager	3/5
	NAVAIR 533	Comp. and Software Agent	2/20
	FCDSSA(SD)	Maintenance Agent	2/25-28
	Grumman	System Contractor	3/20
P-3C	NAVAIR 533	Comp. and Software Agent	2/12
	NADC	Advanced Development Agent, System Contractor	3/5
S-3A	NAVAIR 533	Comp. and Software Agent	2/12
	Lockheed	System Contractor	3/5
F-14	NAVAIR PMA 241 VM	Program Manager	3/7
	NAVAIR 5331	System Development Agent	2/20
	NMC, Pt. Mugu	Maintenance Agent	3/12
	Hughes, Los Angeles	AWG-9 System Contractor	5/20-21
	Grumman, Pt. Mugu	F-14 Contractor	5/22

E-2C TACTICAL DATA SYSTEM

E-2C TACTICAL DATA SYSTEM

2. E-2C TACTICAL DATA SYSTEM

2.1 GENERAL SYSTEM DESCRIPTION

The E-2C is a carrier-based airborne tactical data and control system that provides radar early warning, passive detection, interceptor, and strike control capabilities.

The E-2C evolved in early 1970 from the E-2B and was deployed in September 1974. Primary improvements over the E-2B involved the addition of a passive detection system (ALR-59), a new radar (APS-120), and a new display system (APA-172). The E-2C uses the same L-304 computer as the E-2B. The Navy software maintenance organization, Fleet Combat Direction Systems Support Activity (FCDSSA), was a party to the software development phase, becoming involved in the early stages by assisting NAVAIR in writing the Functional Operational Specifications. Naval Air Test Center (NATC) and COMOPTEVFOR also provided support. A development contract (fixed price and incentive) was awarded to the system development contractor, Grumman Aerospace Corporation, with a separate line item for software development. Software design, generation, and validation were conducted by Grumman using the software facility and system integration test site at their Bethpage facility. The software program was heavily documented. Direct FCDSSA involvement in the review and approval of the Grumman test and evaluation plans proved highly beneficial to program reliability upon system deployment in September 1974. Transition of software from the contractor to Navy maintenance control was relatively smooth because of FCDSSA involvement in the development phase.

The E-2C Airborne Tactical Data System (ATDS) uses three programmable computers. A dual-processor L-304F computer is the central processor. It performs the multisensor tracking and correlation, navigation and intercept vectoring, data link communication, and display generation functions. Special purpose computers are used in the passive detection and navigation systems. Figure 2-1 shows a schematic of the E-2C tactical data system, and Fig. 2-2 shows the system in more detail.

An extensive correlation capability combines responses from radar, passive detection, IFF, and data links. The system has a capability of 300 radar and IFF tracks and 350 passive detection reports and remote tracks, for a total track capacity of 650.

The E-2C airborne system can accomplish the following objectives:

1. Detect, identify, and track airborne and surface targets;

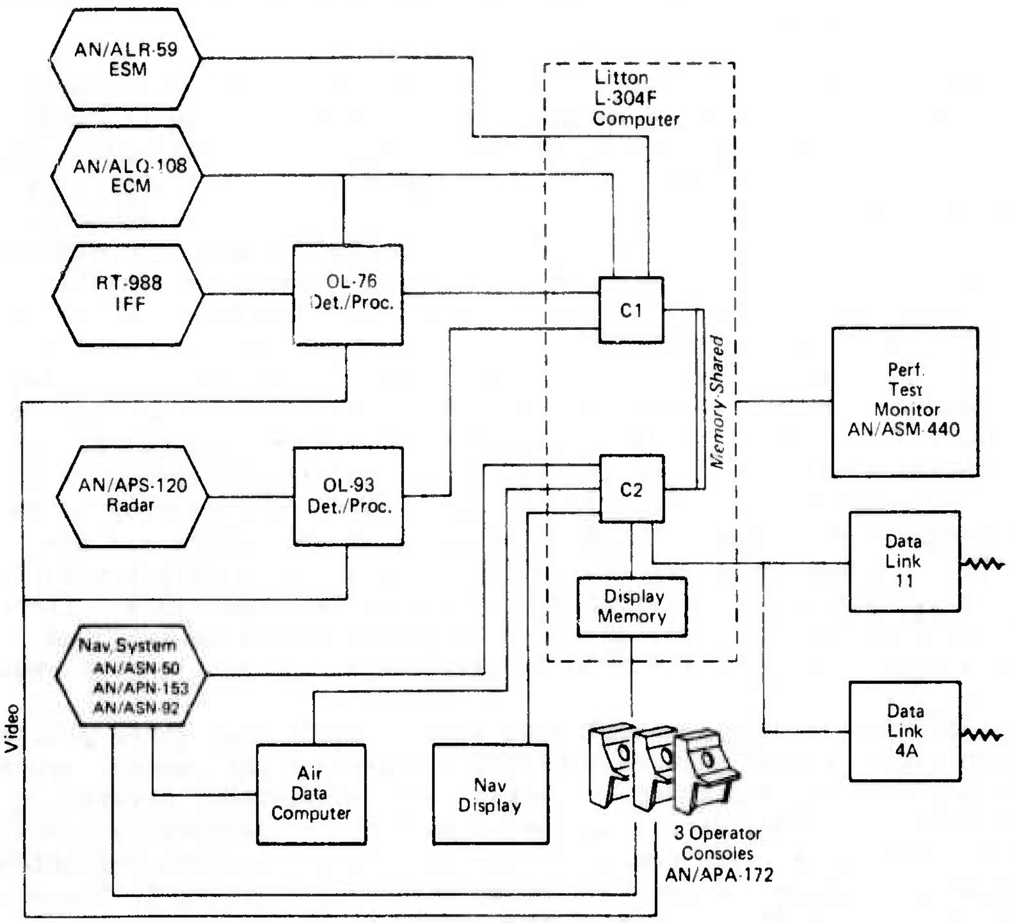


Fig. 2-1 E-2C Tactical Data System Schematic

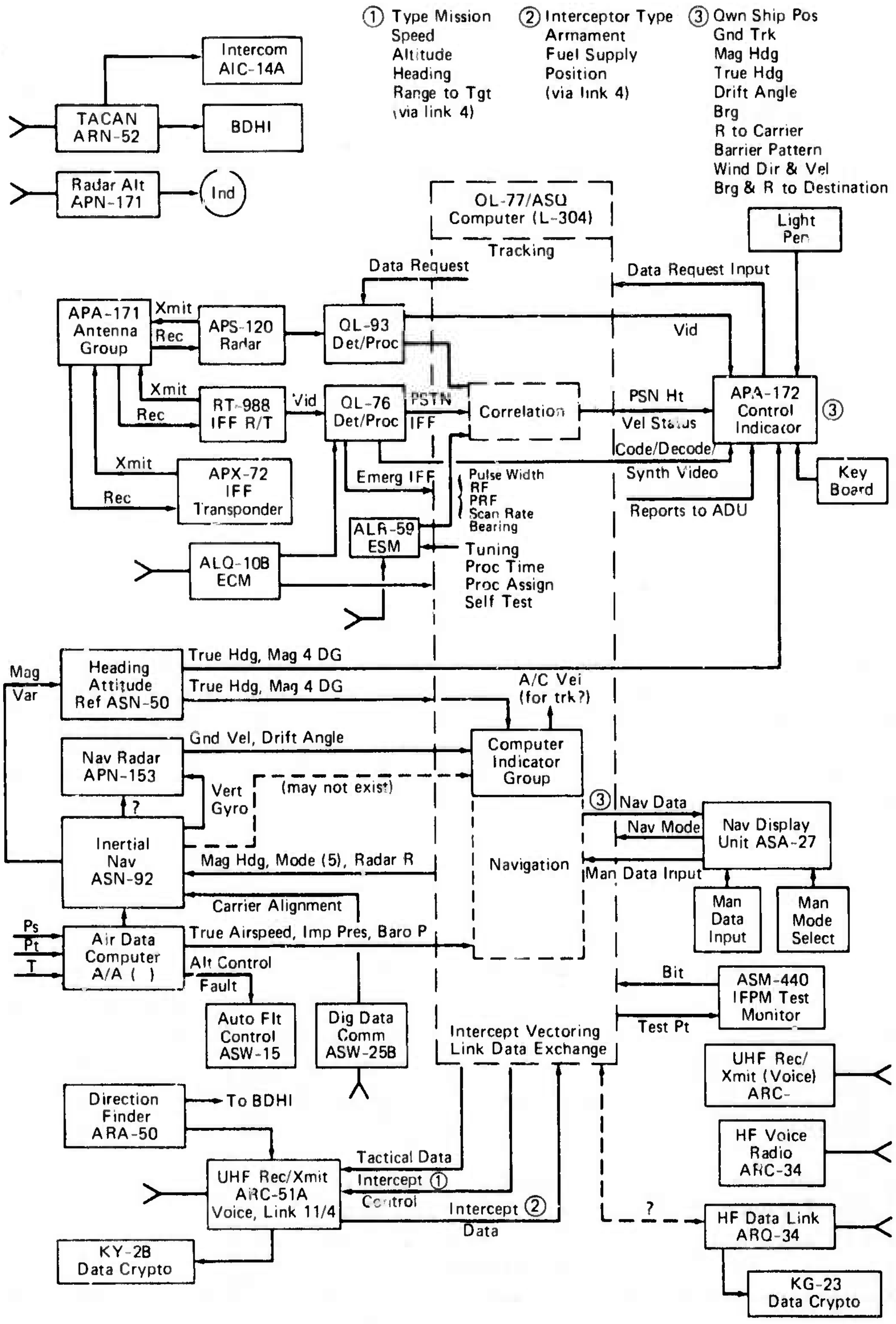


Fig. 2-2 E-2C Tactical Data System

2. Perform threat assessment;

3. Receive and display status information on interceptor and strike aircraft;

4. Receive and display tactical data from the Naval Tactical Data System (NTDS), the Marine Tactical Data System (MTDS), and other tactical data aircraft;

5. Compute, display, and transmit command data for control of interceptors and strike aircraft; and

6. Compute, display, and transmit tactical data to the NTDS and MTDS.

2.2 COMPUTER SYSTEM ARCHITECTURE

2.2.1 Computer Characteristics

The E-2C AEW system uses three programmable computers. A dual-processor L-304F computer is the prime central processor. It performs the tracking, navigation and intercept vectoring, data link communication, and display generation functions. An ARMA-1808 computer is used in the Passive Detection System (PDS) to identify and classify radar emissions. An LC 728 computer is used in the Navigation System. Only the L-304 computer and program will be examined in detail in this report. A summary for the L-304F computer is shown in Table 2-1.

TABLE 2-1

E-2C COMPUTER SUMMARY

Unit	Type	Function	Processor	Memory
C1	Litton L-304 (OL-77/ASQ) (32 bit, 2.2 μs)	Sensor processing and correlation Link 11 control, test, and monitoring	1	80k
C2	Litton L-304 (OL-77/ASQ) (32 bit, 2.2 μs)	Navigation, display, intercept/strike control, Link 4 control, test, and monitoring	1	

After deployment of the E-2A aircraft, the requirement for improved reliability in the computer system led to a replacement of the drum computer used in the E-2A. At that time, in the mid-1960's, the L-304 computer was the best choice for aircraft use where size, weight, and computer processing power were considered the key factors. A dual-processor configuration was selected to provide a large growth margin in the computing system. A hardware configuration was selected that permitted the use of up to 80,000 words of memory. The E-2B was the first airborne multiprocessing system.

The L-304 computer deployed for the E-2C has a memory capacity of 64k words (expandable to 80k). There are two CPU's, each with a memory cycle time of 2.2 μs and the capability for 64 levels of interrupt with eight hardware registers per level. Each processor also has six clocks that can generate interrupts based on specified countdown times. The L-304 also has a dedicated 4k memory module that performs the display refresh function. The display symbol stroke data and the file of symbol parameters to be displayed are contained in this memory and are updated by the computer program.

A single magnetic tape is used in the system for the purpose of loading any of the available program configurations, the tactical data entry, and for data extraction. For example, the contents of a recently deployed load tape are given below:

Bootstrappable Loader,

Fault Isolation Program for the Computer,

Operational Program (two copies) (eight memory module configuration),

Casualty Configuration Program (two copies) (seven memory module configuration),

Passive Detection System Programs (loaded through L-304),

Geographic Point Files (three copies),

Intelligence Files (three copies), and

Data Extraction Files.

2.2.2 Interrelation Among Computers

While the application programs in the L-304 computer are allocated to specific CPU's, the system data are shared between the two CPU's in common memory. The rules for use of common memory and the interlock involved between CPU's are handled entirely within the application program. Input/output (I/O) interfaces to external devices are also dedicated to particular CPU's, but in case of an I/O failure both the associated task and the I/O function can be switched to the other CPU. Inter-CPU interfaces are generally data only. Inter-CPU interrupts are used very little. For the most part, common data usage does not require CPU lockout for data changing. The primary functions that require lockout are additions and deletions of tracks to the track file because of the chain linkage required within the track file.

The L-304 computer and the PDS computer communicate via an I/O channel. The PDS computer program is loaded from magnetic tape via the L-304.

2.2.3 Functional Interfaces with Sensors

The sensor inputs used to perform tracking in the L-304 computer are provided by the AN/APS-120 radar, the IFF Interrogator RT-988/A, and the PDS.

The AN/APS-120 radar is a long-range, high-resolution, airborne early warning radar that provides basic sensor input required for detection of air and surface targets. The radar has an Airborne Moving Target Indicator that permits the detection and tracking of air targets immersed in land and sea return. The AN/APS-120 radar is interfaced to the L-304 computer via the Radar Detector Processor (RDP) OL-93/AP.

The RDP is a special-purpose digital processor that detects echoes present in video signals received from the radar, associates applicable azimuth information with the echo range, determines range displacement of the echo during the detection process, arranges the data in a digital format for the L-304, and delivers such data upon request. The L-304 must associate echoes originating from the same target on separate transmissions in order to determine a centroid azimuth position. It associates multiple returns on a single transmission to determine target height. The resulting centroid position is used for track entry and update.

The IFF Interrogator RT-988/A is an IFF interrogation set that challenges aircraft and identifies friendly aircraft by their response to challenge signals. The IFF transmitter sends out the challenge signals. Replies from friendly aircraft are detected by the receiver and fed to the IFF Detector Processor (IDP) (OL-76/AP) and to the Control Indicator AN/APA-172 for display.

The IDP is a special-purpose digital processor designed to operate on IFF video and to provide position and IFF information on each detected target, in digital format, to the L-304. It also supplies delayed code video, passive decode video, and IFF synthetic video to the Control Indicators. In addition, it automatically alerts the operators to emergency IFF replies. The L-304 must perform the beamsplitting and height determination on IDP inputs, just as it did with RDP inputs.

The PDS AN/ALQ( ) provides threat information to the L-304. The L-304 processes and correlates this information with track data derived from RDP and IDP reports. The PDS contains a programmable computer that interfaces directly to the L-304.

2.2.4 Functional Interface with Displays

The Combat Information Center (CIC) of the aircraft contains three identical display consoles. Each console consists of two CRT's, one in the Main Display Unit (MDU) and one in the Auxiliary Display Unit (ADU). The MDU displays the tactical situation in PPI form, using both computer-generated video (symbols) and raw radar and IFF video. By using a light pen, the operator can "hook" targets on the MDU and can communicate with the computer. The ADU displays computer-stored alphanumerics for any information requested by the operator.

The three operators that man these consoles are the aircraft control officer (ACO), the combat information center officer (CICO), and the radar operator (RO). Although these operator stations have specific names, the system is designed such that any operator console can be used to perform any of the system functions. The allocation of functions to be performed by each operator is made by the CICO depending upon the tactical situation.

The symbol generation, range scale processing, and function button processing are all done in computer software. The refresh function is performed by a special 4k memory module in the L-304. The L-304 can display 250 symbols on each display console.

2.2.5 Interfaces with Navigation Equipment

In order to perform the navigation computing function, the L-304 interfaces with the Carrier Aircraft Inertial Navigation System AN/ASN-92(V) (CAINS), the Doppler Navigation Set AN/APN-153(V), the Air Data Computer (ADC) A/A, the Heading Attitude Reference System (HARS) AN/ASN-50, and the Navigation Display Group.

The CAINS uses the aircraft doppler radar system for inertial damping during flight. During alignment on the carrier, the CAINS accepts carrier position data from the interfaced Ships Inertial Navigation System by a data link system. CAINS may also be aligned on the ground and in flight. The CAINS provides five in-flight modes of navigation: doppler-inertial, inertial, doppler, air data, and attitude heading. The computer is programmed to select the best of these modes. The computer choice can be overridden by the operator at any time.

The Navigation Radar (APN-153) is an all-weather, pulsed radar. It supplies ground speed and drift angle, in pulse form, to the L-304. The doppler radar set operates independently of any ground installation and operates either in conjunction with the CAINS or alone, as a backup system using vertical-gyro information. The combined information from the doppler radar set and from the inertial navigation system is sent to the computer indicator group, resulting in a precise computation of the aircraft velocity.

The ADC A/A-( ) is a solid-state digital computer that accepts air data inputs operating between 75 to 450 kts (true airspeed) and from 1000 to 41,000 ft altitude. The ADC accepts three inputs: static pressure, total pressure, and total temperature. These inputs are converted into analog and digital outputs: true airspeed, impact pressure, barometric altitude, altitude control, and fault signals. These outputs are supplied to the Automatic Flight Control System AN/ASW-15, L-304 computer, CAINS AN/ASN-92(V), and IFPM Test Set-Monitor AN/ASM-440.

The HARS provides heading and attitude information in the form of continuous signal outputs representing the displacement of the aircraft about the pitch, roll, and azimuth axes. The Signal Data Converter (SDC) CV-2867/ASN-50 in the HARS is the digital interface between HARS and either the L-304 computer or Control Indicator AN/APA-172. The SDC provides a secondary derivation of true heading using magnetic heading (from HARS) and magnetic variation inputs in synchro format from CAINS. The SDC converts the true heading and magnetic heading data to serial-digital format.

The Navigation Display Group consists of Computer Control Panel C-3488/ASA-27, Navigation Control Indicator C-3489/ASA-27, Navigation Coding Unit MX-3308/ASA-27, and Power Supply PP 6642/AS. Computer Control Panel C-3488/ASA-27, located in the cockpit, controls the input of navigation data to the L-304 computer by selecting the desired navigation mode. Navigation Control Indicator C-3489/ASA-27, also in the cockpit, displays navigation data processed by the L-304 computer and has controls for manual insertion of data into the L-304 for processing. Navigation Coding Unit MX-3308-ASA-27, located in the nose, distributes power and signals to Computer Control Panel C-3488/ASA-27 and Navigation Control Indicator C-3489/ASA-27.

2.2.6 Functional Interfaces with Communications Equipment

The L-304 computer is interfaced with Receiver-Transmitter AN/ARC-51A and Data Radio Set AN/ARQ-34 in order to perform its interceptor control funtion and to provide tactical data to NTDS aboard the aircraft carrier or other E-2C aircraft. The AN/ARC-51A provides UHF Link 11 and Link 4 operation as well as UHF voice communication. The AN/ARQ-34 provides HF Link 11 operation.

2.2.7 Functional Interfaces with In-Flight Test Equipment

The In-Flight Performance Monitor (IFPM) Test Set-Monitor AN/ASM-440 detects faults within the aircraft avionic systems and assists the operator in isolating the system malfunctions to the Weapon Replaceable Assembly (WRA) level. Six Signal Data Converter CV-2866/ASM-440 units are used as the interface between the L-304 computer and the avionics equipment to store and transmit fault (alarm) information and operator-actuated commands to initiate diagnostic tests and to select critical test points for remote display. The signal selected for display is fed through the multiplexer unit. This unit is a solid-state device that can select any one of 128 test points from 15 different equipments for routing to the CIC compartment. The test signal is then displayed on Oscilloscope OS-144/ASM or Multimeter ME-252/ASM.

2.3 COMPUTER PROGRAM ARCHITECTURE

2.3.1 Program Architectural Structure

In the L-304 assembly language nomenclature, the complete tactical program consists of programs, subroutines, tables, and items. The programs are simply core allocations for a set of subroutines, and they correspond to a major function of the total program, such as tracking, navigation, etc. These programs will be referred to hereafter as subprograms. Each subprogram may contain several different sections corresponding to different tasks. Each section consists of several subroutines. One of these subroutines is an Executive that calls the other subroutines as required. Some subroutines also call each other indirectly.

The program executes in a dual computer, multiprocessing configuration. Specific functions are assigned to each computer with a few functions, such as the Executive and File Control, being executed by both. Conflicts in data accessing between the two processors are avoided by carefully splitting up the processing in terms of time and geographic areas. Various functions are performed sequentially on particular data items, so that both processors do not simultaneously access the same data.

Each of the various sections of the subprograms is assigned a fixed priority level within the appropriate processor. The multiple real-time clocks are used to generate interrupts at various rates to cause periodic interrupt calls to particular program levels. Once a particular level is executed it can generate an interrupt that, in turn, causes transfer to another program level. This in effect generates a call from one subprogram to another. The levels for each function are carefully chosen so that data conflicts do not result from a program being suspended by a higher level interrupt program that operates on the same data.

As an example of the subprogram organization, the tracking subprogram contains subroutines to perform the following functions:

1. RDP/IDP I/O Control,
2. RDP/IDP Echo/Report Processing,
3. Report/Track Association,
4. Report/Track Correlation,
5. Tracking, and
6. Track File Control.

These subroutines are executed in sequence to process each 8° sector of data. Each of these subroutines is executed at a different priority level in the processor. Information is passed from one subroutine to the next via data files.

The program structure is modular in the sense that functions are isolated into relatively independent sections of code. However, it is not modular in the strictest sense because control can flow directly from one module to another and is not under the control of a central, scheduling executive.

2.3.2 Program Executive Functions

The Executive subprogram performs several housekeeping and diagnostic functions, but it does not do scheduling operations that are typically performed by an Executive. The Executive function is performed by assigning the 64 levels of interrupts available in the processor to the various functions. With dedicated hardware registers for each level of interrupt, an interrupt uses only about 12 μs of overhead time, and the Executive program is not involved in requesting or processing an interrupt. Interrupts are generated periodically by the six countdown clocks and also on demand by the subprograms themselves.

The scheduling type of Executive was carefully studied but was rejected because of execution time considerations. The study concluded that a scheduling Executive would add 5% overhead and that under heavy loads this would cause program execution to exceed 100% of the available time. If load leveling between the two processors had been a problem, a scheduling Executive would have been advantageous. But load leveling problems were avoided by carefully allocating the functions to each processor so that they were loaded equally.

The Executive performs the program initialization function. It is then run alternately in each processor at a 200 ms rate in each. It services certain operator requests dealing with system restarting data recording, diagnostic execution, and fault monitoring. It periodically schedules the Signal Command Readout and Alarm Module (SCRAM) subprogram, which performs in-flight performance monitoring. It monitors diagnostic error indicators provided by other subprograms and notifies the operator of these errors.

The Executive performs a cross check each time it is called to determine if the other processor is operating. If the other processor is "hung up" in an I/O loop, it attempts to correct the problem by switching to the other processor. If the problem persists, it switches to the one computer mode.

The Executive/System Control subprogram occupies 3200 decimal, 32 bit words in core. It executes for approximately 500 μs out of every 200 ms (0.25%) in the normal, no fault mode.

2.3.3 Subprogram Functions

The L-304 subprogram functions include tracking, navigation and interception vectoring, data exchange via Data Link, and generation of display data. To perform target tracking, the L-304 processes target reports from Radar Detector Processor Group OL-93/AP, Detector Processor Group OL-76/AP, and displays target status (threat or nonthreat), position, height, and speed. The entered data are instrumental in updating previously stored information, in sending tactical data via Link 11 to the NTDS aboard the aircraft carrier or the ATDS of other E-2C aircraft, in turning over certain decision-making functions to the L-304, and in assigning and directing interceptor aircraft manually or via Link 4 automatically. Link 4 data and Link 11 input data are automatically correlated with local radar and IFF tracks. The tracks from the PDS are manually correlated with other tracks.

The system has a tracking capacity of 300 radar and IFF tracks, 350 remote tracks, geographic points, and PDS tracks. The total track capacity is 650; the original E-2C specification called for 300.

During the interceptor control function, each interceptor assigned to the aircraft transmits information on interceptor type, armament, fuel supply, and position to the L-304 (via Data Link) where it is evaluated and either stored or used to update previously stored information. When an interceptor is selected to engage a target, the L-304 generates type of mission, speed, altitude, heading, range-to-target, etc., and transmits this to the selected interceptor by the Data Link System.

During the navigation computing function, the L-304 processes data from CAINS AN/ASN-92(V), from Doppler Navigation Set AN/APN-153(V), from Air Data Computer A/A, from HARS AN/ASN-50, and navigation data manually entered by the pilot or copilot. The L-304 generates and displays to the pilot and copilot ownship position, ground track, magnetic heading, true heading, drift angle, bearing and range-to-carrier center, barrier pattern, wind direction and speed, and bearing and range to destination.

The E-2C subprogram functions are listed in Table 2-2, which briefly describes the functions and lists the Central Processing Unit (CPU) that executes the module. In some cases, different CPU's execute different parts of the same subprogram. In these cases the CPU that does most of the processing is listed.

TABLE 2-2

TACTICAL SUBPROGRAMS

Subprogram	Primary Function	CPU
Executive	Detects and records faults, schedules IFPM function, processes operator program control actions and displays.	A, B
Navigation	Controls I/O to CAINS, doppler, HARS, and ADC navigation systems. Evaluates and displays Navigation Panel data. Updates ownship position.	A
Track	Processes RDP and IDP sensor data, correlates sensor data with tracks, updates tracks, controls track add/drop function.	B
Displays	Performs I/O for 3 CIC consoles. Generates track symbol displays, alphanumeric displays, and alerts. Processes operator inputs.	A
Intercept/Strike Control	Performs computations necessary to effect vectoring assignments against aircraft or stationary targets.	A
Link 11	Controls Link 11 I/O. Formats and deformats messages. Performs grid lock and automatic/live association.	B
Link 4	Controls and processes all incoming and outgoing Link 4A messages. Maintains link timing and formats, and deformats messages.	A
Passive Detection	Controls operation of PDS via control mesages. Accepts reports from PDS and generates passive tracks.	
General Machine Test	Verifies operation of processors and memory.	A, B
SCRAM	Controls and monitors hardware IFPM functions.	A, B

2.3.4 Program Time and Core Requirements

The core and time usage were carefully managed throughout the E-2B and E-2C history in order to accomplish the required functions with a minimum of computer resources. The original E-2B configuration contained two processors and 56k of 32 bit word length memory. Additional memory modules could be added with no hardware or software modification, up to a maximum of 80k. The original E-2B program used only 40k of memory and could have been done with one computer. The two-computer configuration was chosen for the capability of expansion to meet future system requirements.

The E-2C tactical program occupies the entire 64k of memory in the current L-304 computer configuration. An extra 16k expansion capability is still available as was required in the program specification.

The program currently uses 95% of the available time in processing. The approximate core requirements of individual subprograms are listed below:

Executive		3.2k
Navigation		1.7k
Tracking		20.5k
Displays		17.5k
Interrupt/Strike Control		2.6k
Link 11		6.0k
Link 4		1.5k
Passive Detection		6.4k
SCRAM and GMT(IFPM)		3.6k
	Total	63.0k

The E-2C is now being modified to operate with the Advanced Radar Processing System (ARPS) radar. This will require an additional 8k of memory. Short-range future requirements will require modifications to the computer to obtain more memory and faster execution. It is also anticipated that more capable preprocessors will be used to decrease the computer data load. Long-range future requirements (1990) will require a new computer.

Throughout the development of the E-2C program, computer time and core limitations caused several problems that required specific attention to resolve.

Due primarily to program requirements that were not anticipated, the processor time resource was saturated under certain conditions. The function that required the greatest amount of computer time was the association of radar detections with tracks in the track file. Also, certain operator actions resulted in considerable processor usage. To meet the processor time constraints, certain functions had to be deleted or reduced in scope, and the technique of using more memory to save processor time was used. Certain time-consuming functions were optimized to the extent possible.

The update of the display console symbology is performed by using a dedicated 4k memory module that is part of the L-304 computer. The display symbol stroke data and the file of symbol parameters to be displayed are contained in this memory and updated by the L-304 computer. The memory update function is a time-consuming computer function and, as a result, posed some problems to the system design.

While the L-304 computer is capable of accepting 10 memory modules of 8000 words each, only 8 memory modules are used in the deployed system. The spare memory slots are not usable in the current system in order to guarantee growth potential. Because of the number of functions performed and the large files required, memory limitations became a serious problem in E-2C development.

When the E-2C radar was initially operated at Long Island, the combination of real and false tracks immediately overloaded the system track capacity of 300 tracks. When operating the E-2C at an altitude of 2500 ft, the radar and IFF easily see more than 300 actual tracks in its coverage out to 250 mi. When operating on the ground, the IFF routinely sees between 170 and 200 tracks. To limit the number of tracks, operator functions were defined to limit the coverage of the radar.

2.3.5 Automatic Diagnostics and Casualty Capabilities

Several automatic diagnostics and some automatic casualty reconfiguration are used in the E-2C program. The General Machine Test (GMT) verifies the correct operation of the processor instruction execution logic. It is the lowest priority program function and is continually cycled.

The SCRAM subprogram performs the majority of all hardware IFPM functions. It is executed periodically every 2.5 to 4 sec or immediately upon operator request. The SCRAM tests include test targets, alert light test, voltage checks, and certain semiautomatic tests.

The Executive module performs a cross check to determine if the other processor is operating. If a processor determines that the other processor is stopped in an I/O loop, it will switch that I/O function to itself. If the second processor has failed, it will switch to the one processor mode. The Executive also notifies the operator of any faults detected in any other module.

2.4 SOFTWARE DEFINITION, DESIGN, AND IMPLEMENTATION

2.4.1 Software Definition

Extensive documentation was used during the definition phase. The primary requirements definition document for the E-2C system was the E-2C Weapon System Specification. Computer program requirements were derived principally from this document, although the contract also required compliance with three documents prepared by FCDSSA(SD). These three documents (the System Operational Specification (SOS), the Functional Operational Specification (FOS), and the Operational Requirements Document (ORD)) were used primarily as guides.

The SOS defines the requirements of the Tactical Data System Operational Program. The document treats aspects that are primarily related to program maintenance, Fleet use, casualty reaction, diagnostics, and Link 11 planning. The SOS lists the following as pertinent to the specification:

U.S. Navy Book of Standards for Tactical Data

Systems OPNAVINST 05711.91A (NAVTACSTANS).

The FOS is actually a series of specifications. Each specification is to be used as a basis for the design and implementation of a specific function and is to contain limitations and equipment interface data where applicable.

2.4.2 Software Design

Extensive documentation was also used in the design phase. A system design for the tactical program was formulated using the above doucments and a System Analysis Document (SAD). The system design is intended to support the generation of the detailed programs; the design material itself is issued as part of the System Operational Design Document (SODD).

Other software design documents are used to support the SODD (including a guide for the preparation of the SODD). All of these documents (including the SODD itself) are described in more detail in the E-2C Initial Program Plan.

These supporting documents include:

1. System Overall Flow Diagram (SOFD). This diagram includes blocks for all peripheral equipment communicating with the computer, identification of all major program functions, and indicates information flow between blocks;

2. Function Operational Design Document (FODD) is a collection of subprogram designs that are defined in the SODD. The FODD establishes the subprogram performance baseline and all aspects of program design; and

3. Program Technical Description (PTD). This documents the characteristics and capabilities of a particular software function.

Figure 2-3 illustrates the phases of the software development process with an indication of the required documentation at each phase. A more detailed view of software development is shown in Fig. 2-4.

2.4.3 Software Implementation

Various methods, tools, and aids were used in generating the actual code from the design documents.

2.4.3.1 Programming Standards and Manuals

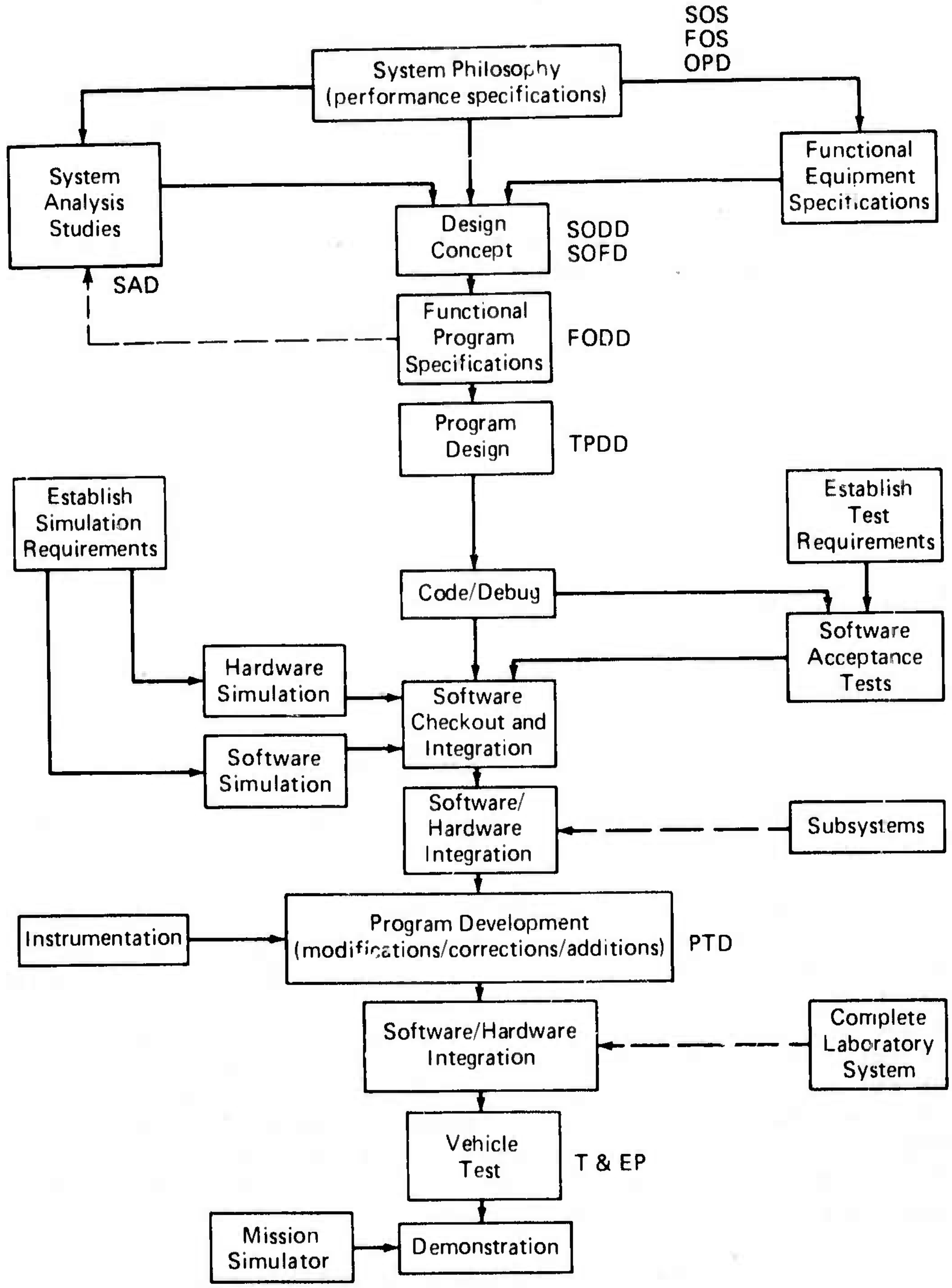
The previously mentioned NAVTACSTANS provides standards for Tactical Data Systems.

An example of a manual used during software implementation is the E-2C Programmer's Reference Manual. This manual is intended to provide all information required by a programmer to convert the diagrammed structure of the operational sequences of a computer program to the instruction code for input to the system computer. The manual is written for the digital computer programmers who will prepare source programs for the operational, test, maintenance, simulation, and interpreter routines for the E-2C Tactical Data System. The manual combines the features of a basic programming manual and a programmer's reference manual and will be used in the training of college-level personnel who have received special system orientation.

2.4.3.2 Language and Program Generation Facility

The LISA Assembler (Litton Industries Symbolic Assembler) was chosen for the E-2C because:

1. The only candidate high-level language at the time (CMS-2) was not fully operational;



Legend

SOS	= System Operational Specifications	FODD	= Functional Operational Design Document
FOS	= Functional Operational Specifications	SAD	= System Analysis Document
ORD	= Operational Requirements Document	TPDD	= Technical Program Design Document
SODD	= System Operational Design Document	PTD	= Program Technical Description
SOFD	= System Overall Flow Diagram	T & EP	= Test and Evaluation Program

Fig. 2-3 Software Development Schematic

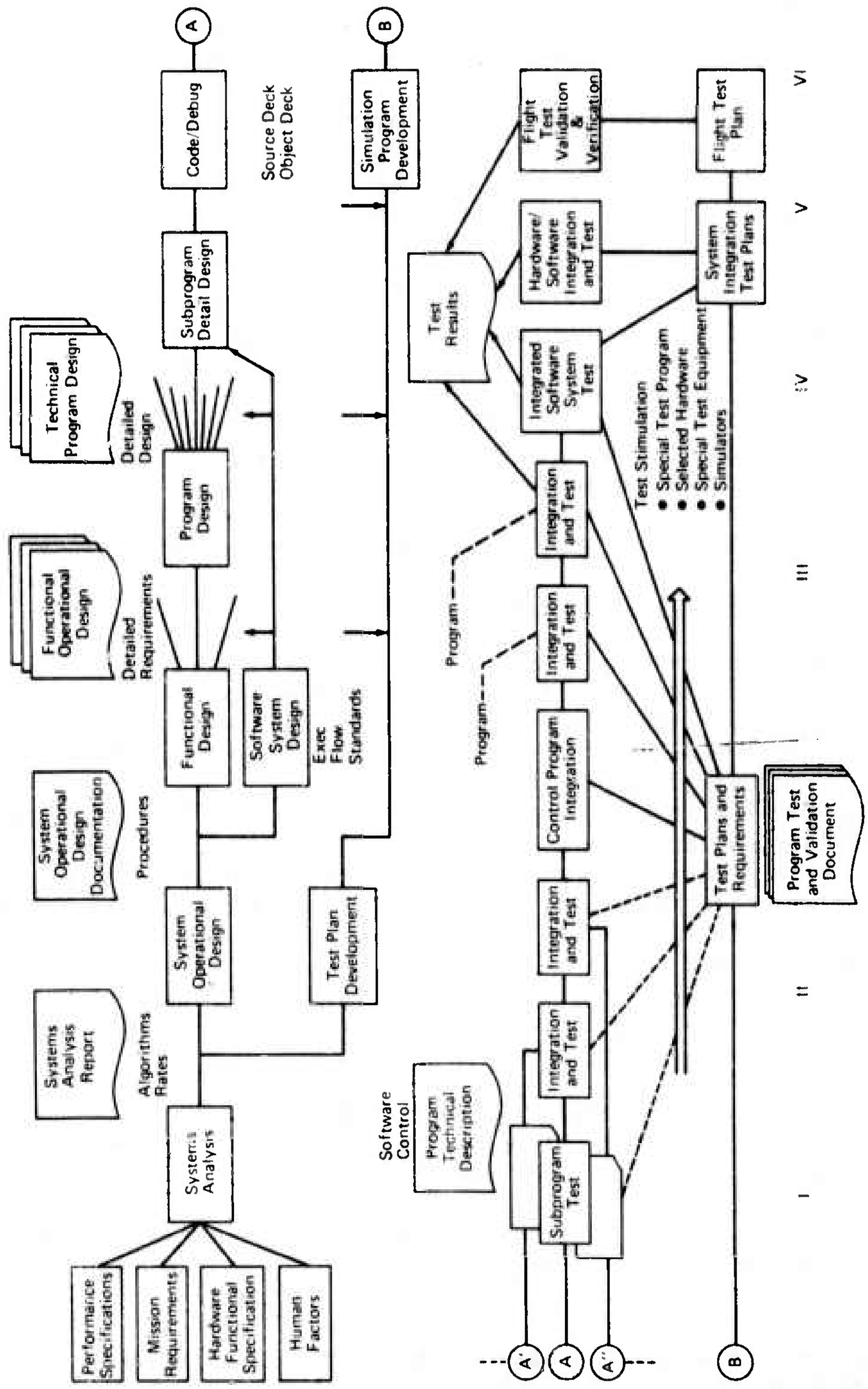


Fig. 2-4 Software Development

2. A CMS-2 compile facility was expensive; and

3. The high-level code generation was inefficient.

While these were valid reasons at the time, Grumman now believes that high-level languages should be used whenever possible even though the efficiency of the program is not as great as with low-level languages. NAVAIR representatives emphasized the point that if a standard Navy language is adopted, the compiler should be written in a machine-independent language so that it can run on commercial systems. This then would not require (expensive) additional Navy equipment (e.g., UYK-7, etc) for program compilation.

All computer program development, checkout, and integration were done at a single facility at the Grumman site. Within the facility, a section was devoted to program assembly operations using the L-304 computer. Also, two sections were available for two integration/checkout benches. By using a flexible computer interface switching system, computers could be reallocated for various functions within the facility.

2.4.3.3 Implementation Organization

The number of people required for program development including documentation support and simulation was about 30 people. The maximum number of tactical programmers employed was 18. The total number of personnel including all test program development was 70 people. The average number over a 5-yr period was 22 people. Not including analysts, the average output was 2.5 instructions per hour. Including analysts' time, about one instruction per hour was achieved. One hundred and seventy-two thousand words of programming and 50,000 pages of documentation were generated. Grumman considered the programming team to be exceptional in terms of their talents and motivations. The high level of motivation resulted because the job was interesting, a team effort was used, and management trusted the programmers to deliver the product without extensive internal reviews. The total cost of the software development contract was $9,000,000.

In the opinion of Grumman, the integration agent for a system should be the same agency that does software development. A number of problems had been experienced by Grumman in developments in which this was not the case. In the case of E-2C, Grumman was the integration agent and they also performed the software development activity. However, in E-2A and F-2B the software was developed by Litton and FCDSSA, respectively.

Three examples are given showing the need for a responsive software development agent:

1. During the development phase of a contract, changes are inevitable due to oversights in the initial design or due to errors in analysis of hardware performance. As a result, the software development agency must be responsive to changes without adding excessive cost or schedule delay.

2. In the checkout phase of development the problem with an independant software development agent is that a system problem must be isolated explicitly to be software before the software agent will take corrective action. By the time the integration agent has found the source of the problem, he could just as easily correct the problem and do without the software agent.

3. During the Board of Inspection and Survey (BIS) for the E-2C, the E-2C met the Weapon System specifications, but the BIS team evaluates the system on its operational utility, not whether the system meets the specification or not. In this case, certain requirements of the E-2C were not met in the view of the BIS Committee and in a period of 5 weeks Grumman revamped the system to meet their requirements. In the opinion of Grumman, this would not have been possible if arrangements with a separate software development agency had been required.

2.5 SOFTWARE VALIDATION AND INTEGRATION

The computer program and checkout process was done by the philosophy of build-a-little, test-a-little. Original planning schedules for E-2C programming showed the classic phases of design, coding, checkout, and integration. However, programming managers knew that to perform all coding without any checkout and integration would be disastrous. In addition to planned phasing of elements of the program through the integration process, a number of uncontrolled events affected the development sequence that included delays in development of hardware and in requirements to demonstrate progress through demonstration of the program.

A test team was assembled within Grumman Aerospace Corporation (GAC), independent of the programmers, to evaluate the program operability. On other programs at Grumman, a common technique has been to assemble a small team for the purpose of trying to defeat the system. In another related activity, a team will postulate a program fault, determine the symptoms that such a fault will cause, and then present these symptoms to another group whose job it is to determine what the cause of the problem is. One of the uses of such an activity is to determine exactly what functions should be monitored in the equipment.

The software test plan was prepared jointly by GAC and FCDSSA. A more comprehensive and meaningful test resulted. The test phase was very successful in that it exposed many problems that were corrected, resulting in a very reliable deployed system. Integration tests at a test site uncovered about 70% of the problems with the remainder discovered in flight tests. In all, about 500 trouble reports were issued over the 3-month test period.

The main integration/test facility is at Grumman (Long Island) and includes all actual avionics hardware. A second facility exists at FCDSSA, which is used for program maintenance and development of new features. NAVAIR expressed the opinion that a single site for integration, test, program development, and checkout was not desirable (two are preferred) due to the varying requirements of facility users. Much time is wasted in determining what configuration the system is set up for and converting to a different setup when required.

The following three programs are support programs for software integration and validation.

2.5.1 ATDS Monitor/Operating System

The Airborne Tactical Data System Monitor/Operation System (AMOS) is a monitor control program together with associated subprograms for the Digital Data Computer OL-77/ASQ. AMOS is designed to perform the following functions:

1. Control the loading of object programs,
2. Handle Digital Data Computer OL-77/ASQ data processing peripheral equipment,
3. Provide diagnostic communications to the operator, and
4. Minimize the degree of operator setup and intervention required to assemble source and execute object programs.

2.5.2 Mission Simulator

The E-2C Mission Simulator has been developed to substitute controlled inputs in place of the actual sensor data for the purpose of checking out the E-2C Tactical Program. The simulation system uses a digital computer to produce the desired inputs at a real-time rate, synchronized with the E-2C computer and an interface network to match the simulator computer I/O to the E-2C I/O devices. All communications between the simulator computer and the E-2C system are via the Simulator Interface System (SIS).

Several levels of software requirements are required for the specific testing of the E-2C Tactical Program. Each level is designed to check out a different part of the overall E-2C Tactical Program, with all leading to a full mission simulation program to provide a laboratory operation representing actual flight environment. The simulation hardware consists primarily of the Varian 6201 Digital Computer and GAC-designed SIS. Characteristics of each are:

Computer System

1. 16 bit word
2. 1.8 μs cycle time
3. 12,288 word magnetic core
4. 16 priority interrupts
5. 1 ms, real-time clock
6. Direct memory access
7. 2 buffer interlace controllers
8. 2 magnetic tape controllers
9. 3 9-track 800 bpi magnetic tape
10. ASR 35 teletypewriter
11. Line printer
12. Card reader
13. High-speed punched tape reader

Interface System

1. 20 input registers (16 bit) serial to parallel
2. 20 output registers (16 bit) parallel to serial
3. 4 dual direction registers (16 bit)
4. 14 control commands
5. 5 status sense lines
6. 16 interrupt lines

2.5.3 Data Extraction/Data Reduction

Support program requirements for the test evaluation phase of the E-2C programming effort consist, as a minimum, of data extraction, data editing for all recorded data, and data reduction (analysis) subprograms for selected data groups. Data extraction is defined as recording on the tape or printer selected core data in binary format. Data editing is the printing of recorded data in an interpreted format (decimal values of speed, heading, position, etc.). Data reduction is the derivation of analytical data by computational analysis of the recorded data groups (sigma deviations, error biases, true versus computer values, etc.).

2.6 SOFTWARE ACQUISITION MANAGEMENT ORGANIZATION AND METHODS

2.6.1 Management Organizations and Information

The primary organizations involved in the E-2C system acquisition are:

1.	Program Office	NAVAIR	
	Program Manager	Capt. F. H. Roth W. L. Wagner	PMA-231 PMA-231A
	Computer and Software Group	P. L. Luppino C. F. Showalter	(E-2C/ARPS) NAVAIR 533 (E-2C)
2.	System Contractor	GAC	
3.	Software Contractor	GAC	
4.	Validation Agent	GAC	
5.	Integration Agent	GAC	
6.	Maintenance Agent	FCDSSA(SD)	
	E-2C Managers	Cdr. J. Dage D. Smith	

The software deliverables included the Operational Program, and Functional and Design Description documents.

The Program Office made use of their in-house Computer and Software Group in an advisory role. This group established general policies and procedures generally not available because of the inadequacy of OPNAV-generated specification instructions. It was felt that instructions in existence at that time (and to a lesser degree in 1975) actually increase costs when attempts to assure compliance are made.

Grumman was given the responsibility for software development together with the E-2C system development contract. Software development was specified as a separate line item in the system contract, which was fixed price with incentive. The total software development cost (including R&D, procurement, and documentation) came to approximately $13,000,000, which is half the E-2C aircraft per unit cost of $26,000,000. The software contract called for substantial documentation. Clauses contained in the contract included approval rights on test plans and an agreement to accept program changes requested before specified dates at no extra cost. Software deliverables included documentation, program card decks, program listings, and Tactical System magnetic tapes in both IBM and E-2C system language.

FCDSSA was tasked under separate contract to support NAVAIR in the areas of program definition/specifications, program and document review, and test planning. Extensive Navy involvement in generating comprehensive test and evaluation plans contributed significantly to delivery of a system that has demonstrated excellent operational performance. FCDSSA involvement throughout the development phase also resulted in a smooth and rapid transition of software control from the contractor to the Navy maintenance organization.

2.6.2 Management Techniques

The total E-2C system performance responsibility was contracted to Grumman to avoid a division of responsibility that proved costly on the previous E-2B development. Grumman provided the examples cited in Section 2.4.3.3 to illustrate the need for a responsive software development agent.

The use of a common software and system integration agent also allowed to a greater degree the use of overall system performance specifications in lieu of separate hardware and software performance specifications. This allows the contractor to exercise independent control over software design and freedom in making hardware-software tradeoffs.

2.6.2.1 Design Review Process

During the development process, design reviews were held between Grumman and the Navy in which Grumman presented the design status of the software in an informal way. Software development activity was driven by the program schedule and required periods where extra work shifts and long work weeks were employed.

2.6.2.2 Quality Assurance

No quality assurance requirements were specified for E-2C software development. Grumman programmers did their own quality assurance. A better approach would have been to form an independent quality assurance group to report to the same level of management as the design groups.

2.6.2.3 Configuration Control

The L-304 CPU was used in the E-2B and was retained for use in the E-2C. No control over software design was exercised by the Navy, and no formal acceptance and sign-off of design documents were required by NAVAIR. Engineering change procedures were prescribed in the contract, which specified dates before which the contractor would accept changes at no additional cost to the Navy. These changes were limited to prescribed areas. No change would be made that exceeded the hardware constraints in the contract without NAVAIR approval.

The contract clause requiring approval of test and evaluation plans proved highly beneficial. However, these documents were received by NAVAIR shortly before the test phase was scheduled to begin. Many deficiencies in the documents made this a serious problem. The problem was solved only because a one-year slip in the program permitted NAVAIR and FCDSSA to work with the contractor to revise the plans. The test revisions subsequently resulted in the deployment of a system that has demonstrated excellent operational performance.

2.6.3 Management Documents

The primary management documents were the E-2C Weapon System Specifications (SD-527-2) and the E-2C System Operational Specifications (SOS-8400) referred to in the contract. Two additional control documents, the FOS and the ORD, were provided to the contractor after initiation of the contract. As a result, these documents were used by GAC as guidance rather than as specifications.

2.6.4 Documentation Requirements

The software contract called for extensive documentation. The following items are a partial listing of these:

Initial Project Plan,

System Operational Design,

Functional Operational Design,

Validation and Verification Plan,

Configuration Control Procedures,

Overall System Flow Diagram,

*Functional Test and Evaluation Plan,

*Flight Test and Evaluation Plan,

*Integrated System Test and Evaluation Plan,

*System Performance Summary,

Design Mannual, and

Operational Manual.

Documents marked with an asterisk required Navy review and approval. It appears that documentation requirements may have been excessive, and Grumman expressed the opinion that present standards result in excessive duplication among documents.

2.7 OPERATIONAL SOFTWARE MAINTENANCE

FCDSSA(SD) assumed the life cycle maintenance of E-2C on 1 September 1974. A test facility was installed and was largely operational at FCDSSA by March 1974. FCDSSA was brought into the E-2C development as a consultant during the design process providing the necessary experience for the role of life cycle maintenance. Both NAVAIR and FCDSSA emphasized the early involvement as necessary for smooth transition to maintenance.

In terms of achieving a reliable computer program, the E-2C has been extremely successful. In more than 1200 hr of flight time since deployment there have been no identified software failures. The computer hardware mean time between failure is 150 hr. Grumman credits the good reliability of the program to extensive testing at the land-based facility.

2.8 HIGHLIGHTS

System growth requirements were recognized in the E-2C system definition with the result that a second L-304 processor was provided for growth. This 100% margin was expected to more than absorb anticipated growth and computer load due to hardware uncertainties. However, largely because of increased radar data processing requirements, all of the margin was used, causing costly tailoring of the software to meet system requirements. (SE2)

GAC had a complete integration and test facility for the E-2C that contained all the actual hardware used in the system. It also had provisions for simulating many of the hardware interfaces. A similar facility was developed at FCDSSA(SD), the Operational Support Facility. The E-2C program has had a very good reliability record, having logged 1200 hr with no software errors. GAC attributes a large part of this success to the extensive testing of the system. (IP3)

The E-2C Program Manager (PM) uses the NAVAIR Computer and Software Systems Group (Code 533) as technical support and review agent with success. The same agency is used by several NAVAIR PM's for this purpose. (MS2)

FCDSSA(SD) was tasked by NAVAIR under separate contract to provide support in the areas of E-2C program definition/specifications, program and document review, and test and evaluation planning. FCDSSA(SD) assisted NAVAIR in the preparation of requirements documents. (MS2,MS3)

Extensive Navy involvement in creating comprehensive test and evaluation plans contributed significantly to delivery of a program that has demonstrated excellent operational reliability. Navy involvement throughout the development phase also resulted in a smooth transition of software control from the contractor to the Navy support organization. (MS3)

P-3C AIRBORNE PATROL SYSTEM

3. P-3C AIRBORNE PATROL SYSTEM

3.1 GENERAL SYSTEM DESCRIPTION

The P-3C is a land-based Antisubmarine Warfare (ASW) patrol aircraft, with the mission to perform ocean surveillance, strike group and convoy protection, and mine-laying operations. Detection, classification, and weapon delivery against surface and subsurface targets are basic requirements.

The system is capable of performing operations independently or as a unit in a coordinated operation. It has communications and data link equipment to allow it to perform coordinated operations. Maximum endurance during either of these types of operations is about 14 hr.

Electromagnetic, infrared, and acoustic sensors are used together with the visual capabilities of the crew.

The airframe itself is a version of the Lockheed Electra originally produced for commercial air carrier operations. The four turboprop engines provide speed capabilities on the order of 350 kts and can be used in two and three engine operations to provide extended endurance.

The aircraft system includes inertial, doppler, LORAN, and TACAN navigation units. The data processing system uses this and other tactical information to drive commands to a flight director system for use by the pilot.

Development started at the Naval Air Development Center (NADC) about 1960. It was originally pointed toward solving the S-2 tactical coordination problem and then shifted to the larger P-3 airframe.

A Mod 0 lab system was configured around a 32k, 30 bit CP-901 computer. There followed a Mod 1 flying configuration, a Mod 2 lab version, and finally a Mod 3 flying version that used an updated 64k memory of the CP-901.

The Navy began the P-3C program using the digital program in hand at NADC. In 1968 Lockheed received the NADC Functional Requirements Specifications (FRS).

A Software Management Team was established by PMA-240 who delegated control to NAVAIR 533. The remai[illegible] Univac, General Electric, NADC, and Fleet Combat Direction Systems Support Activity, Dam Neck (FCDSSA(DN)). Periodic design reviews were held, and design approaches were validated and demonstrated at the Integration Test Facility. VX-1 ultimately conducted an OPEVAL.

Upon delivery to the Fleet, FCDSSA(DN) took over maintenance support responsibility. Eight major versions of the program have since evolved.

Version A of the P-3C Operational Program was delivered by Lockheed in January 1969. At that time a Software Configuration Control Board (SCCB) was formed. In July 1969, version C was delivered. Version F, including ESM functions, was also delivered by Lockheed. FCDSSA(DN) has developed subsequent versions.

Figure 3-1 shows a schematic of the P-3C System. Figure 3-2 shows the P-3C system block diagram in more detail.

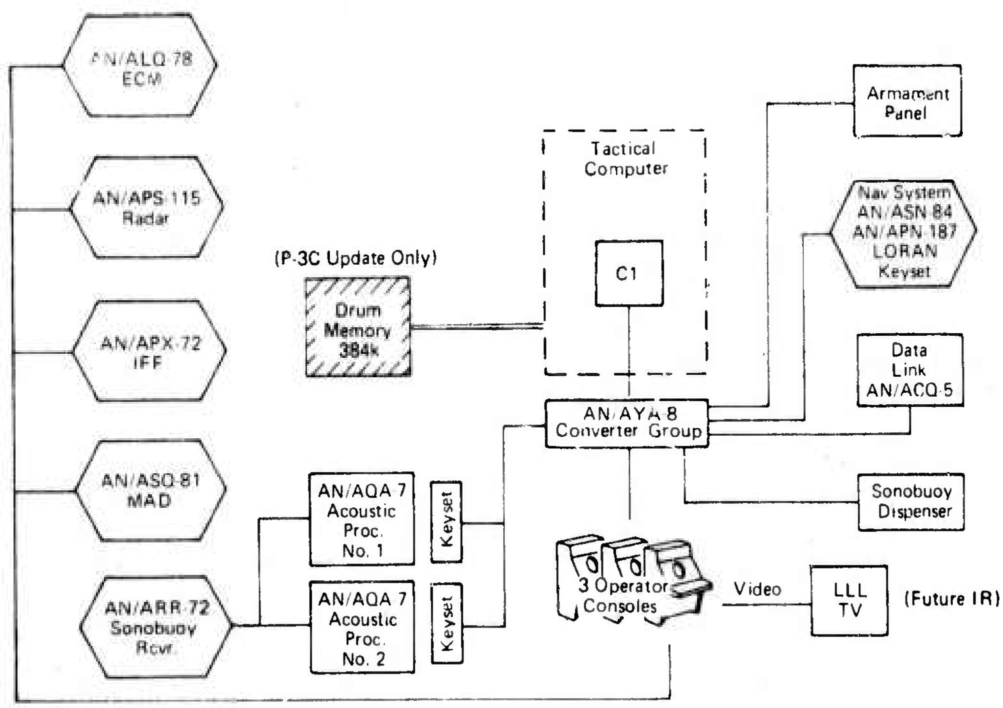


Fig. 3-1 P-3C Airborne Patrol System

The latest event in the airborne ASW digital program effort is the P-3C update wherein a drum has been added to the basic P-3C computer giving it a seven-fold increase in memory capacity.

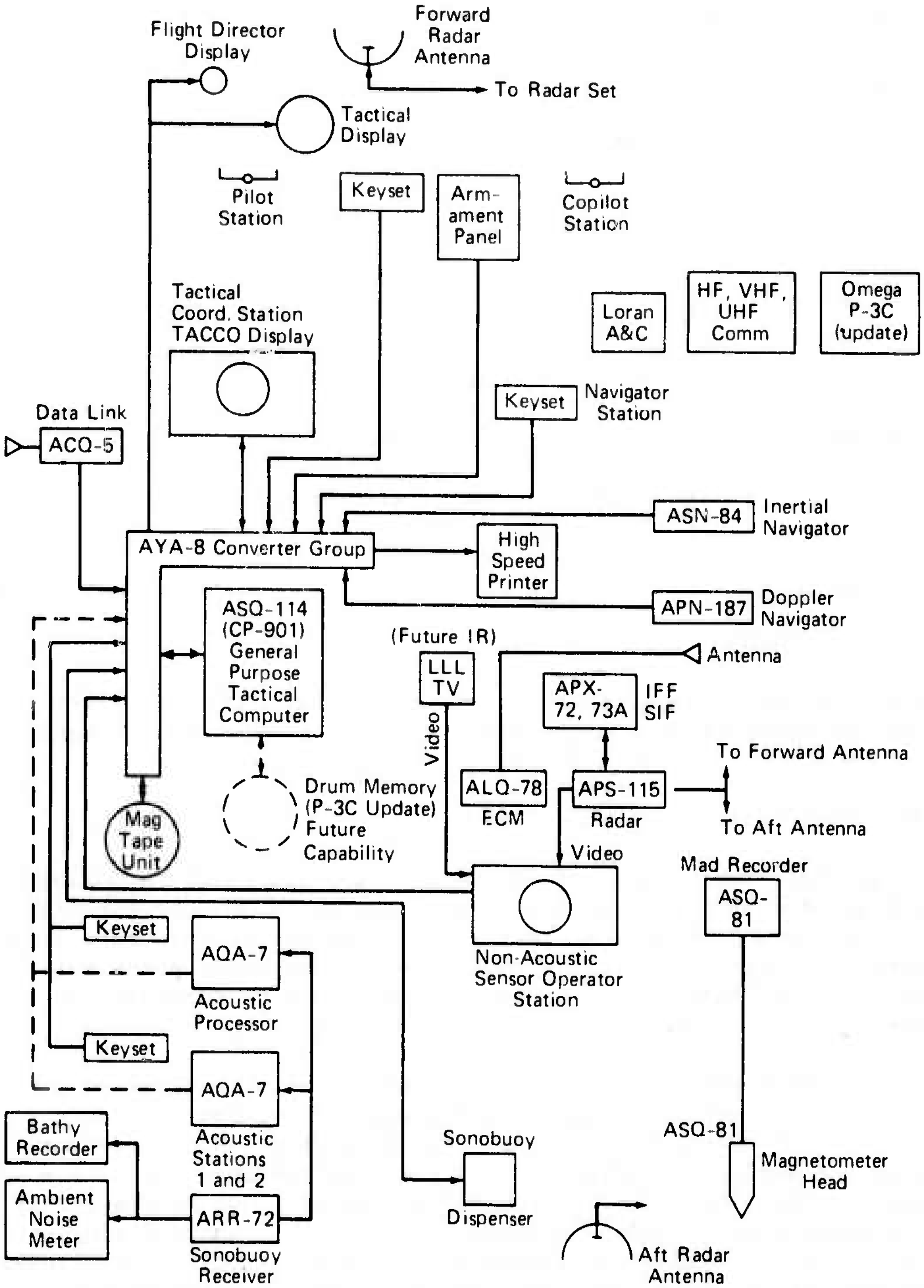


Fig. 3-2 P-3C System Block Diagram

3.2 COMPUTER SYSTEM ARCHITECTURE

3.2.1 Computer Characteristics

Table 3-1 gives a summary of the computer used in the P-3C System.

TABLE 3-1

P-3C COMPUTER SUMMARY

Unit	Type	Function	Processor	Memory
C1	CP-901/ASQ-114 (30 bit, 2 μs)	Navigation, storage of operator entered positions from sensors, sonobuoy tracking, stores inventory, stores auto drop control, display control	1	64k

3.2.2 Computer Update

The P-3C update expands the tactical computational capability of the P-3C by the addition of a drum memory. The drum adds 393,000 words of core to the 64,000 already existing in the CP-901 computer.

3.2.3 Functional Interfaces with Sensors

In general, the outputs of the sensors are displayed in analog fashion and entered into the data processing system by an operator via a display console or a "keyset" terminal. The exception to this rule is a mode of operation wherein digital outputs from the acoustic processor are received and an "automatic detection" function is performed. The results are printed on the high-speed printer to alert the operators.

The acoustic processor used in conjunction with received sonobuoy signals can perform narrowband low-frequency detection and recording for the received sonobuoy signals. The types of sonobuoys used are both passive and active. Passive capabilities include omni and directional signal processing. The current preprogrammed pinging, range-only active buoy processing is being modified to include a commanded pinging capability as well as multimode frequency operations. Active directional capability will be provided when the buoy capability is introduced to the Fleet.

Acoustic environmental data processing units include a recorder for displaying the output signals from an expendable bathythermograph sonobuoy and a meter for monitoring the ocean ambient noise.

The nonacoustic sensors include a radar, ECM set, Magnetic Anomaly Detector (MAD), and currently a Low Light Level TV (LLLTV). The LLLTV is being replaced with an infrared system.

3.3 COMPUTER PROGRAM ARCHITECTURE

The tasks or functions performed by the computer fall into two major categories: (1) tactical or operational, and (2) pre- and in-flight testing.

3.3.1 Tactical Program Functions

1. Keeping track of aircraft position;
2. Storing sonobuoy positions and associated target bearings, ranges, fixes, and track vectors;
3. Storing operator inputs of Visual Radar, ECM, and MAD target positions and track vectors;
4. Performing drift correction and stabilization computations for sonobuoys;
5. Performing acoustic fixing and prediction computations for the ASW functions;
6. Computing the vector commands for the flight director system and the pilot's display;
7. Keeping track of loaded and expended stores of sonobuoys and weapons;
8. Comparing aircraft position and intended drop points and automatically releasing stores according to preprogrammed parameters;
9. Accepting inputs from pilot, acoustic operator, and navigation keysets as well as inputs from Tactical Coordination Station (TACCO) and Nonacoustic Sensor Operator general-purpose displays;

10. Accepting commands from the ordnance panel and TACCO console and initiating launcher drop commands; and

11. Processing the various inputs, grouping data, and providing appropriate display symbology for the TACCO and Nonacoustic Sensor Displays.

The expanded core from the update provides room to perform the following functions:

1. Improved Navigation (worldwide Omega and Transit);

2. Acoustic and ESM classification;

3. Sonobuoy Location System operations;

4. Tactical satellite communications;

5. Program protection and degraded mode operations; and

6. Tactical Support Center briefing/debriefing data.

3.3.2 Testing Program Functions

In addition to the operational tasks, the computer is also used to perform preflight system go-no-go (SYGNOG) operations. In this mode the operational program is replaced by a series of programs that performs interface as well as larger system level tests. One important feature is a test that operates in conjunction with the built-in test equipment of the AQA-7 acoustic processor to determine the operability of the sonobuoy receiver, acoustic processor, and recorder subsystems operating together. The results from the entire test series determine whether or not the aircraft is ready to perform its tactical mission. If not, the program diagnostic tests are used to assist in fault location. The diagnostics can also be used in flight. The expanded core from the update provides improved system test operations to enhance this capability.

3.4 SOFTWARE DEFINITION, DESIGN, AND IMPLEMENTATION

3.4.1 Software Definition

The advent of nuclear, high-performance submarines made radar, visual, and ECM detection processes secondary to acoustic sonobuoy detection and tracking. In addition, acoustic processing techniques were rapidly advancing toward passive direction-finding as well as active buoy capabilities. The classification of passive submarine signatures, though conceptually simple, was complex from the total number of features used and their harmonic relationships.

Fortunately, NADC had been party to much if not all of the airborne acoustic sensor development and through familiarity with the problem were able to recognize what needed to be done to improve the situation. Their experience with digitally driven displays for other systems also proved helpful.

As stated earlier, development at NADC started around 1960, originally involving S-2 tactical coordination. The work was then shifted to the larger P-3 airframe.

Using the digital program in hand at NADC, the Navy began the P-3C program. This modification to the P-3B program retained the basic types of sensors but included new versions of them. The contract to Lockheed started out initially for the equipment only, with the Navy supplying the computer program under NADC auspices. The contract then changed to include provision of the software by Lockheed.

In 1968 Lockheed received the NADC FRS. These FRS documents were not in accordance with WS-8506 or similar standards. They were used to develop coding and design specifications.

3.4.2 Software Design

The computer used was GFE and was chosen as a part of the NADC Mod 3 effort. It represented little or no risk in the context that it had been part of the prototype development.

The CS-1 language and compiler were also GFE. The Executive program is basically a table scanner, and some redundant code exists in the program.

From an overall design standpoint and realizing that the basic program operates in a single CPU system, the design is straightforward.

3.4.3 Software Implementation

The creation of the computer program by Lockheed became largely one of redoing the functions that had already been demonstrated feasible by virtue of having the NADC prototype. The significance of this was obviously that the chance of achieving success was high. In fact, about 20% of the production programmer team had previously been on the NADC prototype program.

A significant starting point for the P-3C production software occurred when Lockheed received the contract from the Navy. The equipment with which the already specified computer was to interface was government-selected and government-furnished. In order to digitally communicate with these units a group of converters and logic units was necessary.

The computer programming started with the operational program and was followed by the equipment go-no-go and diagnostic test programs. Program listings themselves provided the final form of documentation. The original NADC Mod 3 listings were used as references during the production software development.

Since the equipment was GFE, the documents describing the equipment operations were not tailored for use by programmers. Lockheed instituted a Programmers Technical Manual (PTM) for each item of interest. These PTM's were written to describe the equipment operation in such a way that a programmer would understand the digital input-output interface reactions.

3.5 SOFTWARE VALIDATION AND INTEGRATION

A very critical part of the acquisition process was the development and availability of the Integration Test Facility, which preceded coding. The early use of this to validate code was considered critical.

This test facility was made up of the major sensor, display, and computer interfacing equipment as well as the computer itself. Code was checked out in segments relating to individual subsystems and then brought together into a total system.

3.6 SOFTWARE ACQUISITION MANAGEMENT ORGANIZATION AND METHODS

3.6.1 Overall Management

Program Manager	PMA-240
System Contractor	Lockheed California Co.
Type Contract	Cost plus incentive fee (most equipment GFE)
Software Contractor	Univac
Validation Agent	VX-1
Maintenance Agent	FCDSSA(DN) (will be NADC in future)

Software Deliverables	Operational program, system test programs, diagnostics, functional requirements specifications, coding and design specifications, program listings
Integration Agent	Lockheed California Co.

A Software Management Team was established by PMA-240 who delegated NAVAIR 533 to be chairmen. The remaining team members were Lockheed, Univac, General Electric, NADC, and FCDSSA(DN).

Weekly meetings were held and features, improvements, and problems were discussed. Items for incorporation or change were given priority based on criteria that included whether or not the item was mandatory for running the program or just desirable, its cost impact, and its schedule impact. A steering committee vote was then taken to designate appropriate action items.

Periodic design reviews were held, and design approaches were validated and demonstrated on the Integration Test Facility. VX-1 ultimately conducted an OPEVAL.

Standard management tools were used by Lockheed/Univac in the sense that persons were given responsibility and test demonstrations were carried out at progressive levels of coding. Problem sheets were generated, and appropriate solutions were produced. Frequent recompiles were made to keep the computer up to date.

3.6.2 New Development Management

The drum P-3C update, previously mentioned, is a major departure from the previous procurement of software. The Navy itself, using NADC, is designing and developing the program. The extensive Integration Test Laboratory at NADC has provided the same type of development facility as the one used by Lockheed. This step was taken by the Navy in order to achieve an alternative to sole source software procurement.

Operating as a prime contractor, NADC made up a bid package for the software on a CPFF basis. Twenty functional specifications were written, and the program compiler chosen was the CMS-2Q (CMS-2 Version Q). Programs are debugged on a batch process "desk simulation" as well as on a "hot bench" mockup in the Integration Test Laboratory. The performance of the system is monitored at the Computer Program Design Specification (CPDS) level.

NADC has followed a process of creating the program in levels A through G. These levels culminate in about 500 programs being tied together to accomplish a set of prespecified tasks. Testing is completed at each "build level" prior to creating a new "build".

The program itself was recompiled about every 5 weeks. NADC considered that they were best able to respond to change while the product was being built by following this build level approach.

3.7 OPERATIONAL SOFTWARE MAINTENANCE

Upon delivery to the Fleet, FCDSSA(DN) took over maintenance support responsibility. Eight major versions of the program have evolved in the interim.

Version A of the P-3C program was delivered by Lockheed in January 1969. At that time, when first delivery was being made to an operational squadron, an SCCB was formed. In parallel with this a Product Improvement Board (PIB) addressing equipment was formed. Again, through the use of the Integration Test Facility, corrections and/or modifications to both hardware and software were validated. In July 1969 version C was delivered for maintenance and modification to FCDSSA(DN). Version F including ESM functions was also delivered by Lockheed. From then on, FCDSSA has developed version G and the H series (H.A, H.B, H.C, and H.D), which constitute major recompiles.

Since its introduction to the Fleet, the P-3C program has been corrected and modified using the following procedure. A responsible coordinator at each of the two Fleet Patrol Wings wherein P-3C aircraft are assigned is given the task of soliciting and cataloging inputs from the people in the individual patrol squadrons. Errors discovered in the program are written down and constitute a mandatory "fix list" for FCDSSA. Modifications recommended by Fleet personnel are considered and listed in order of priority. Some are rejected by the SCCB on the basis that they are not considered useful enough to warrant the change. This list is then passed on to FCDSSA who then combines it into the overall list of things to be done to the program.

The Fleet ASW System Tester (FAST) is a computer simulation facility that is used by FCDSSA to make changes to the program. After changes are made, the new tape is carried to an operational unit, and operability is verified by an FCDSSA representative.

3.8 HIGHLIGHTS

The contract to Lockheed was originally for the equipment only, with the Navy supplying the computer program under NADC auspices. The contract was subsequently changed to include provision of the software by Lockheed. Lockheed's task then was to redo the functions already demonstrated in the NADC prototype. About 20% of the production programmer team had previously been with the NADC prototype program. (MP1)

The GFE computer was chosen as a part of the NADC Mod 3 effort. It represented little or no risk since it had been part of the prototype development. The selected airborne computer was chosen as the constraining factor in program size. The CS-1 compiler was also GFE. (MP1,SE1,IP1)

The Functional Requirements Specifications were not in accordance with WS-8506 or similar standards. They were used to develop coding and design specifications. Program listings themselves provided the final form of documentation. The original Mod 3 NADC listings were used as references during the production software development. (MP3)

Since system test programs actually comprise three to four times as much code as the operational program, they should be given proper attention from the beginning and should be given equal priority with the operational program. (MP3)

Based on the experience of the P-3C software development, the digital program developers indicate the need for a more structured programming approach to producing the final product. Along with this, a need was recognized for a "system level" document that would address hardware and software interactions and requirements in the same context. This would fill the gap between an operational level specification and the program functional requirements specification. (SE1)

The original computer used in P-3C had 32k words of memory. During development the computer was enlarged internally to 64k. The recent P-3C "Update" incorporated a 384k drum to perform expanded functional capabilities. System test programs comprise three to four times as much code as the operational program. (SE2)

Since the equipment was GFE, the documents describing its operations were not tailored for use by programmers. Lockheed instituted a PTM for each equipment of interest. These PTM's were written so that a programmer would understand the digital input-output interface reactions. (IP2)

A well-planned integration facility should be allocated from the beginning. Its life cycle usage for program maintenance and modification can help amortize its cost. (IP3)

Thus, a very critical part of the acquisition process was the development and availability of the Integration Test Facility which preceded coding. This early validation of code was considered critical. The test facility was made up of the major sensor, display, and computer interfacing equipment as well as the computer itself. Code was checked out in segments relating to individual subsystems and then brought together into a total system representation. (IP3)

Production level management of software requires an understanding of programming at the coding level if sound decisions are to be made. (MS1)

The P-3C update is a major departure from the previous procurement of software. The Navy itself, using NADC, is designing and developing the program. The extensive Integration Test Laboratory at NADC has provided the same type of development facility as the one used by Lockheed. This step was taken by the Navy in order to achieve an alternative to sole source software procurement. (MS2)

Involvement of the life cycle software support agent should be instituted at an early stage. His involvement can include being part of the test and validation team. (MS3)

S-3A AIRBORNE WEAPON SYSTEM

4. S-3A AIRBORNE WEAPON SYSTEM

4.1 GENERAL SYSTEM DESCRIPTION

The S-3A is a carrier-based aircraft with the mission to perform ocean surveillance for convoy and strike group protection. Detection, classification, and weapon delivery against surface and subsurface targets are basic requirements.

The system is capable of performing operations independently or as a unit in a coordinated operation. It is provided with communications and data link equipment to allow it to perform the coordinated operations. Maximum endurance during either of these types of operation is 8 hours.

Electromagnetic, infrared, and acoustic sensors are used together with the visual capabilities of the crew.

The airframe is totally new and designed to meet the requirements within the limits of aircraft technology. Two turbofan jet engines are of special design to meet the dash and loiter speed requirements.

The aircraft system includes inertial, doppler, LORAN, and TACAN navigation units. The data processing system uses this and other tactical information to drive commands to a flight director system for use by the pilot.

When Lockheed was awarded the S-3A contract in 1969, the system experience in both hardware and software was transferred in major degree from the P-3C effort. The major increase in effort was in acoustic processing and classification, and in associated drum storage and display requirements. This award represented the culmination of the NADC ANEW program that was started in 1960. Lockheed subcontracted to Univac, its bid team member, for the software on a fixed price basis. An Integration Test Facility was established at the outset for software/hardware interaction development.

Fleet Issue 1, the first Fleet Operational Program, was delivered in 1974. Fleet Issue 2, delivered in February 1975, is comprised of errata from the Board of Inspection and Survey (BIS). Fleet Issue 3 will include new data link and acoustic classification modifications. Ten operational squadrons will be outfitted with the new system by 1977.

Figure 4-1 shows a schematic of the S-3A system. Figure 4-2 shows the S-3A system block diagram in more detail (excerpted from the Lockheed S-3A Avionics Weapon System Functional Description - LR 23666).

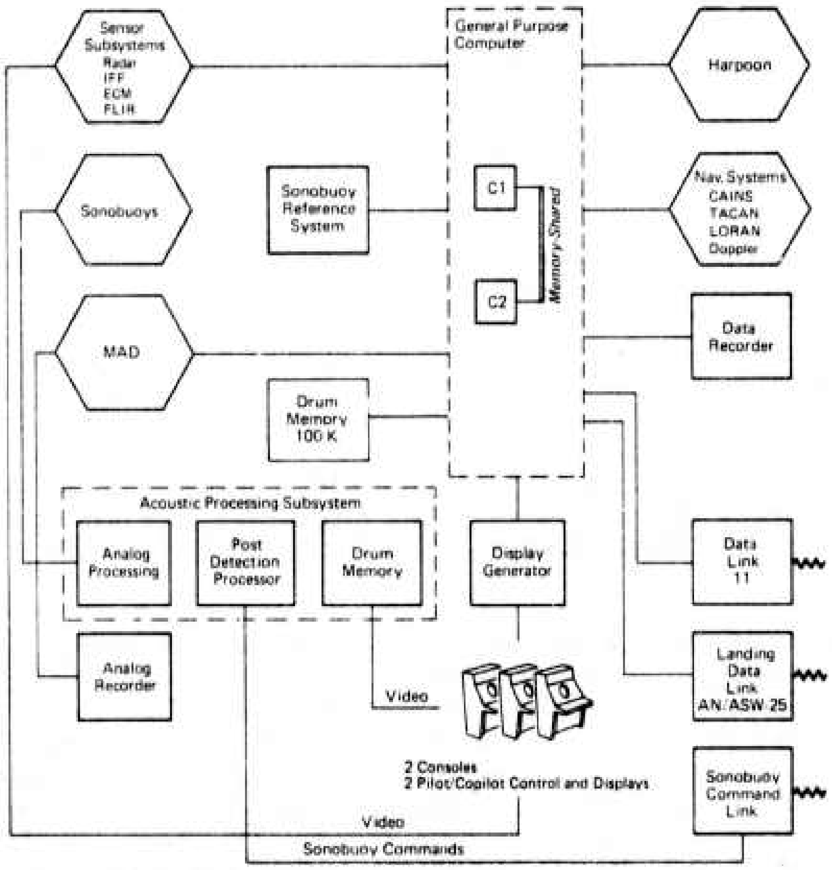


Fig. 4-1 S-3A Airborne Weapon System

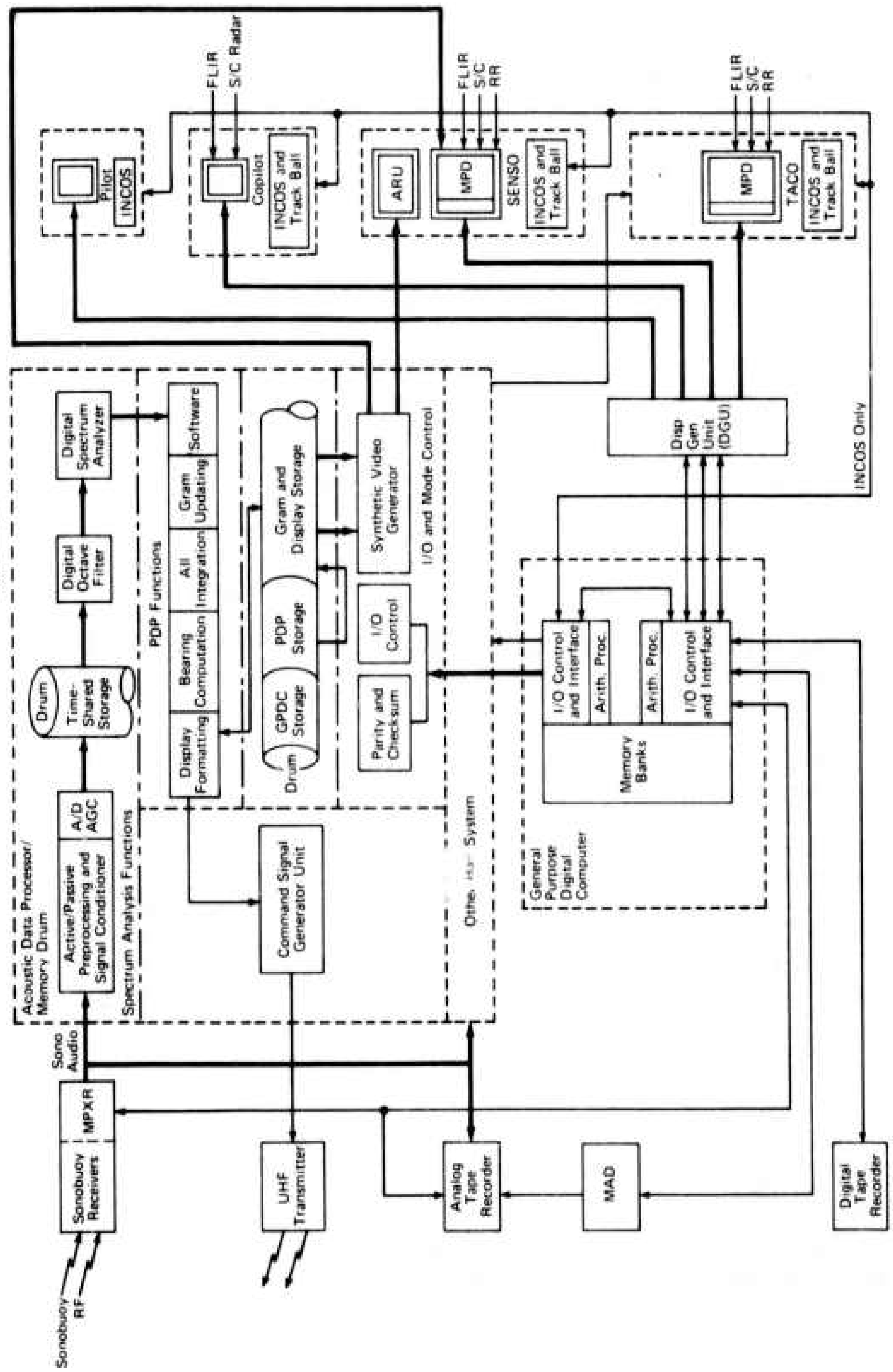


Fig. 4-2 S-3A System Block Diagram

4.2 COMPUTER SYSTEM ARCHITECTURE

4.2.1 Computer Characteristics

Table 4-1 gives a summary of the computer used in the S-3A system.

TABLE 4-1

S-3A COMPUTER SUMMARY

Unit	Type	Function	Processor	Memory
C1 & C2	U 1832 (32 bit + 4 parity, 1.5 μs) AYK-10	Navigation, Harpoon launch control, target tracking, sonobuoy tracking and inventory, target classification, INCOS control, display control, system tests	2 (multiprocessed)	64k

The AYK-10 computer includes two memory drums totaling about 180k words. The CPU is an independent dual processor very similar in operation to the UYK-7.

4.2.2 Functional Interfaces with Sensors, Displays, and Flight Director System

The acoustic processor used in conjunction with reveived sonobuoy signals can perform narrowband low-frequency detection and recording for the received sonobuoy signals. The types of sonobuoys used are both passive and active. Passive capabilities include omni and directional signal processing. The current preprogrammed pinging, range-only active buoy processing is being modified to include a commanded pinging capability as well as multimode frequency operations. Active directional capability will be provided when the buoy capability is introduced to the Fleet.

Acoustic environmental data units include processing for the output singals from an expendable bathythermograph sonobuoy and a measurement of the ocean ambient noise.

The nonacoustic sensors include a radar, ESM set, Magnetic Anomaly Detector (MAD), and Forward Looking Infrared (FLIR).

The sensor outputs and tactical symbology generated by the computer are displayed for the two operator and the pilot and copilot stations directly on the multipurpose display (MPD). Additionally, the computer generates driving signals for the flight director system used by the pilot and copilot. The digital program itself is loaded and controlled via the Integrated Control System (INCOS), which is part of the operator's console and, once loaded, responds to automatic inputs from the peripheral equipment. Unlike former airborne ASW systems wherein the sensors' block boxes were used separately to provide data, sensors are more closely integrated into the combat information systems.

4.3 COMPUTER PROGRAM ARCHITECTURE

The Executive program chosen was an 1108 derivative streamlined to keep down the core and time overhead. The operational program is made up of 18 functionally oriented modules. There are 30k words used for transient data, and 150k are allocated to instructions and data. 10k words (core and drum) are reserved as spare. Only 64k of this capability is resident in the mainframe computer memory.

Some of the code is ULTRA-32 that is generated on a UYK-7. A 642-B computer hosting the XCMS-2 compiler generates XCMS-2 code. A system generator operating on the UYK-7 combines the XCMS-2 and ULTRA-32 codes.

The acoustic data processing system bears special mention since three-quarters of each drum is used. A separate computer (8k MOS) is used to interchange the data and is part of the (Sanders) Acoustic Data Processor.

A data extraction program has been inserted as a common service subroutine throughout the program.

4.3.1 Tactical Program Functions

When loaded with the operational program, the computer performs the following basic operational tasks:

1. Keeping track of aircraft position as a function of navigational inputs;

2. Storing initial sonobuoy positions and associated target hearings, ranges, fixes, and track vectors;

3. Updating sonobuoy positions with the processed Sonobuoy Location System inputs;

4. Storing operator inputs of visual, radar, ECM, and MAD target positions and track vectors;

5. Performing drift correction and stabilization computations for sonobuoys;

6. Performing acoustic fixing and prediction computations for the ASW functions;

7. Comparing the detected input acoustic signatures with a classification table;

8. Computing the vector commands for the flight director system and the pilot's display;

9. Keeping track of loaded and expended stores of sonobuoys and weapons;

10. Comparing aircraft position and intended drop points and automatically releasing stores according to preprogrammed parameters;

11. Accepting operator inputs from the INCOS keysets;

12. Accepting commands from the stores panel and generating launcher drop commands; and

13. Processing the various inputs, grouping data, and providing appropriate display symbology for the General Purpose Displays. This includes sensor data as well as tactical symbology for radar, FLIR, ESM, MAD, and sonobuoys.

4.3.2 Nontactical Program Functions

In addition to the foregoing operational tasks, the computer is also used to perform preflight and inflight system go-no-go and diagnostic operations. In this mode the operational program is replaced by a series of programs that performs interface as well as larger system level tests. One important feature is that programmed tests can request that any piece of equipment perform a built-in test to provide amplifying data on a malfunctioning device. The results obtained from the entire test series are critical in determining whether or not the aircraft is ready to perform its tactical mission. If not, the program diagnostic tests are used to assist in fault location.

An additional set of programs is available to the S-3A for training, mission analysis, and premission preparation. These programs are part of the Weapon System Support Programs and provide the functions implied by their titles.

4.4 SOFTWARE DEFINITION, DESIGN, AND IMPLEMENTATION

4.4.1 Software Definition

The Navy's contract included a high-level functional specification with performance stated for the system but not explicitly for the software. Subsequent to the contract, Lockheed produced a total aircraft system specification that did not suffice as a software specification but did provide a basis for the equipment within which the software had to function. Another Lockheed document, titled "Functional Summary," was the basis for getting Univac to develop the program.

4.4.2 Software Design

As in the P-3C experience, specifications for equipment existed but were not written in a manner oriented for programmer usage. Appendices to the hardware specifications were written to describe the interfaces with the computer. These were called Equipment Functional Flow Descriptions (EFFD's).

From the Functional Specification written by Lockheed, Univac was required to respond by producing Computer Programming Performance Specifications (CPPS) whose format closely resembled that of WS-8506. Review and revisions of these CPPS documents were carried out until accepted by Lockheed. Subsequently, Computer Program Design Specifications (CPDS) and subprogram specifications were written by Univac.

The initial design was iterated as modifications were inserted until such time as the design was frozen. From that point "Software Change Notices" were formally invoked.

4.4.3 Software Implementation

The primary implementation facility used to produce the S-3A programs was the Univac Software Development Facility (SDF). The SDF originally started with a UYK-7, 642-B, and 1832 computer suite for generating ULTRA-32 and XCMS-2 code. Later an MPD with an INCOS tray was installed. Using this together with an emulation program of the drum on the 1832, the ability of this program generation facility was greatly expanded. The initial program modules were built up at this facility prior to checkout at the Integration Test Facility (ITF) and iterated back through as modifications.

4.5 SOFTWARE VALIDATION AND INTEGRATION

Every 6 weeks the Operational Program was checked out at three levels: module, multimodule, and scenario. The scenario level refers to a set of operations whose sequence follows a typical tactical problem.

The ITF contains an Integrated Bench Facility (IBF) for computer interfacing of specific pieces of equipment and performance of end-around testing through use of a patch panel that connected into the larger, more complex suite of S-3A equipment and sensor simulators in the ITF. This IBF includes test equipment, bench test harnesses, a 1230 computer complex, and associated special test software. The ITF also includes a hot avionics mockup for software and hardware integration and debugging.

During 1969 to 1974 about 175 programmers were used to generate 500,000 instructions. Roughly one-third of the effort was used to generate the operational program. Two-thirds was used to generate the system's test and diagnostics as well as the special development test software.

4.6 SOFTWARE ACQUISITION MANAGEMENT ORGANIZATION AND METHODS

Program Status	OPEVAL
Program Manager	PMA-244
System Contractor	Lockheed California Co.
Type Contract	Cost plus incentive fee (most equipment CFE)
Software Contractor	Univac
Validation Agent	VX-1
Maintenance Agent	NADC
Software Deliverables	Operational Program, system test programs, diagnostics, functional requirements specifications, coding and design specifications, program listings
Integration Agent	Lockheed California Co.

The S-3A system was procured by the Navy on the basis of the "milestone" concept, meaning that the S-3A had to pass specified criteria at selected points in its development, both as to cost and technical proficiency. The software as well as most of the equipment was contracted for as Contractor Furnished Equipment (CFE).

From the beginning, a Lockheed/Univac team concept was established and pursued in order to minimize formal documentation requirements. This was considered effective on the basis that the programmers had a fundamental familiarity with the problem and associated equipment types from the P-3C effort.

Lockheed did not actively use the CPDS and subprogram specifications written by Univac to track the program, although they recognized that this level of documentation would be needed eventually by the maintenance support activity. Instead, Lockheed maintained progress checks through functions (i.e., the status of functions being produced against a milestone chart). These were checked weekly, and the entire process was thought to minimize documentation among the working team. The organizational structure was set up such that a Site Manager was in charge. He in turn had Project Engineers (Line Supervisors) for the four major areas:

1. Operational Program,

2. System Test,

3. Support Software, and

4. Integration Group.

The further breakdown within the Operational Program, for example, included:

1. Executive Program Supervisor,

2. Acoustic Supervisor, and

3. Nonacoustic Supervisor.

Group leaders within each of these major functional areas were assigned with supporting programmers and worked on one to two modules as a team.

The initial design was iterated as modifications were inserted until such time as the design was frozen. From that point "Software Change Notices" were formally invoked.

4.7 OPERATIONAL SOFTWARE MAINTENANCE

Fleet Issue 1 (FI-1) (which included fault isolation functional tests) was the major initial program issued for introduction to the Fleet. At that point (1974), the Navy instituted a "change proposal" process for the BIS, NPE, NPA, and OPEVAL process by NATC and COMOPTEVFOR (VX-1). A SCCB was chaired by PMA-244. The software support function is presently being carried out at Lockheed as a level of effort contract. FI-2 was done to perform errata discovered in BIS. FI-3 contains a new data link module and a modification to the acoustic classification module.

4.8 HIGHLIGHTS

When Lockheed was awarded the S-3A contract, much of the system experience in both hardware and software was transferred from the P-3C efforts. The major increase in effort was in acoustic processing and classification, and associated drum storage and display requirements. The Performance Specification was written as a joint effort between the integration contractor (Lockheed) and the software contractor to ensure thorough mutual understanding. The contract for the software was fixed price. (MP1,MP3)

Although documentation was minimized in tracking the functional development in preference to using listings and code, this required a one-on-one personnel requirement. This also resulted in a lack of cross informational exchange and lack of documentation for "add-on" programs, etc. (MP3)

Flow charts were automatically generated from source tapes but were not used in this program. (MP3)

During 1969-1974, about 175 programmers generated 500,000 instructions. Roughly a third of the effort was used to generate the operational program. The rest was used to generate the system's test and diagnostics and the special development test software. (MP3)

The S-3A management of software included milestones listed for each primary "function." The programs were constructed with a building block concept that determined where milestones were logically sequenced. Standard Milestones and Weekly Progress Reviews were used for over 800 separate functions. (AP1)

Frequent module level recompiles (daily or weekly) are considered important in tracking programmer modifications. (AP2,IP1)

Allowing the test people to use their own executive and input-output control methods instead of those of the operational program resulted in redundant operations and I/O testing not entirely representative of system operation. (SE1,SE3,IP1,IP3)

A team concept was used in development, which required that the Design Engineer and Programmer worked together daily and that the engineer understand programming language. (IP2)

A comprehensive integration and test support facility was developed for the S-3A development. Program checkout and a phased sequence of integration steps were accomplished using this facility. The facility, which used both actual and simulated equipment, minimized the need for flight tests to verify system performance. A flying test bed was required for final integration and testing. (IP3)

Not enough preliminary development effort was addressed to operator logic, needs, and operations. This suggests an operator/missions study and simulation effort prior to production for any future programs. (MS3)

F-14 AVIONICS AND WEAPON DELIVERY SYSTEM

WEAPON DELIVERY SYSTEM

5. F-14 AVIONICS AND WEAPON DELIVERY SYSTEM

5.1 GENERAL SYSTEM DESCRIPTION

The F-14 Tomcat is a high-performance carrier-based fighter interceptor that is the platform for the F-14 Avionics and Weapon Delivery System.

The primary mission of the total F-14/Phoenix System is: (a) Fleet Air Defense, (b) Air Superiority — both Beachhead and Escort, (c) Air Combat Maneuvers, and (d) Interdiction.

In support of its stated mission objectives, the F-14 Avionics and Weapon Delivery System has the capability of:

1. Detecting and tracking high-altitude targets at long range, using pulse doppler search (PDS) and single target track (STT) modes;

2. Detecting high-altitude hot targets against a cool sky with the passive infrared search and acquisition sensor;

3. Maintaining 24 simultaneous sensor target tracks using the track-while-scan (TWS) mode;

4. Maintaining eight simultaneous data link (Link 4A) tracks;

5. Looking down for detecting and tracking low-altitude targets;

6. Engaging maneuvering targets in close-in "dogfights";

7. Engaging up to six separate targets simultaneously with the very long range AIM-54A (Phoenix) missiles; and

8. Using all other Navy air-to-air and air-to-ground weapons.

The major components of the F-14 system, other than the airframe itself, are the Sensor System, the Weapon System, AWG-9 Weapon Control System, and the Computer Signal Data Converter (CSDC) Subsystem. Figure 5-1 is a block diagram of the F-14 Avionics and Weapon Delivery System.

5.1.1 Sensor System

The main F-14 sensors are: (a) a long-range radar, (b) a high-resolution infrared system, and (c) an IFF unit. Sensors (a) and (b) are part of the AWG-9 Weapon Control System (WCS).

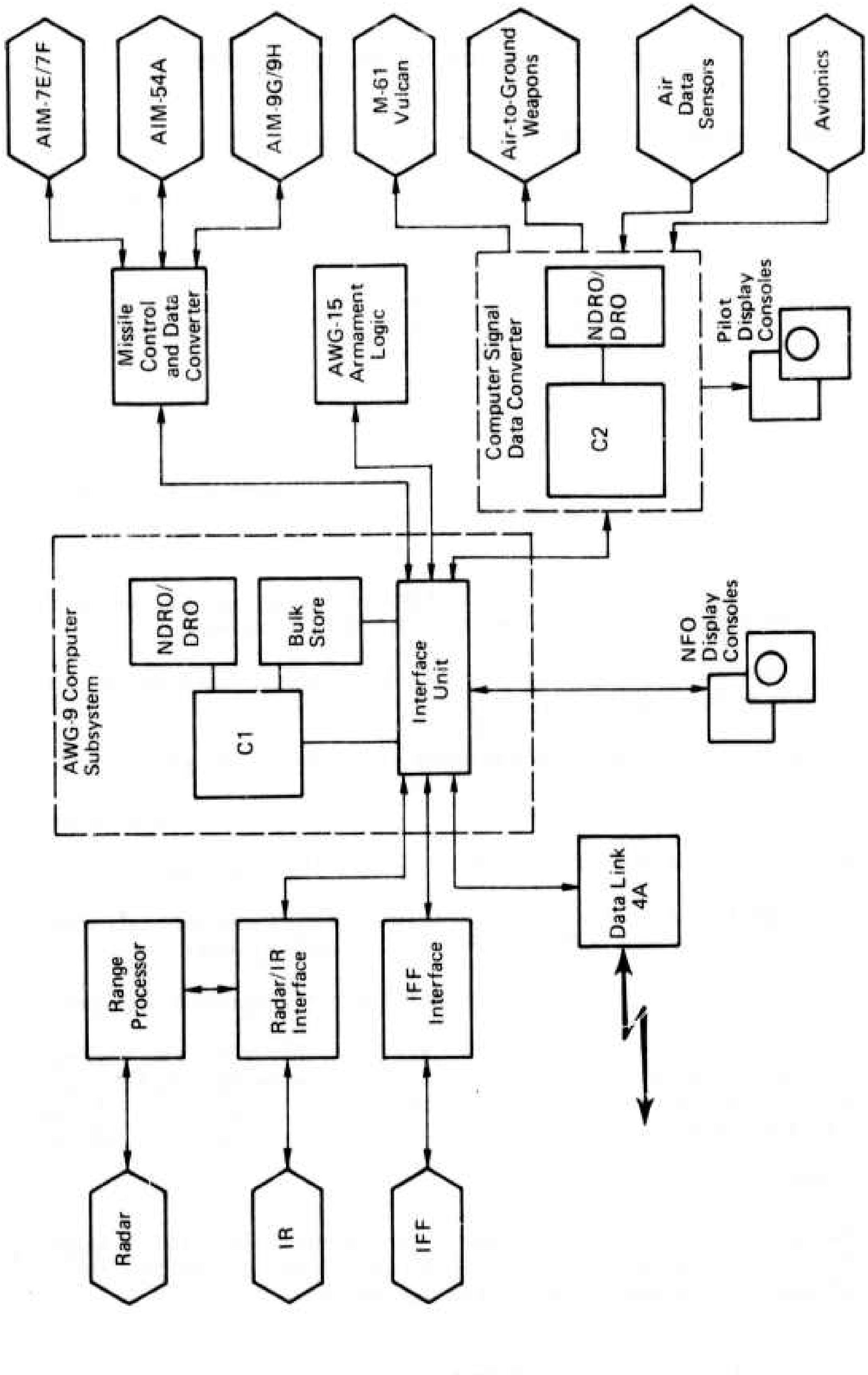


Fig. 5-1 F-14 Avionics and Weapon Delivery System Block Diagram

5.1.2 Weapon System

The armament of the F-14 aircraft is a mixture of the following:

1. Phoenix (AIM-54A) long-range missiles (up to six);

2. Sparrow (AIM-7E/F) short-range missiles (up to six, or a mix of Phoenix and Sparrow);

3. Sidewinder (AIM-9G/H) heat-seeking missiles (up to four);

4. Vulcan (M-61) high-rate-of-fire 20-mm cannon; and

5. Air-to-ground stores (bombs).

5.1.3 AWG-9 Weapon Control System

The AWG-9 System is a Weapon Control System containing two major sensors — a pulse doppler search/track/acquisition/guidance radar and the gimbal-mounted infrared search/acquisition sensor. It includes the CDC 5400B high-speed digital computer, the Tactical Information Display (TID), the Detail Data Display (DDD), and various controls for the Naval Flight Officer (NFO), seated in the second of the F-14's tandem seats, to operate the AWG-9 and launch the aircraft's radar missiles.

All targets are shown symbolically on the TID. They are identified as friendly or hostile, either by the aircraft's radar/IFF (maximum of 24) or from data relayed to the aircraft via Link 4A (maximum of 8). In addition to location and identification, target altitude and course are indicated. The NFO can monitor the DDD to be certain the computer is tracking all targets or to help pick out targets using ECM. The pilot has a repeat of the computer-generated target data coupled into his horizontal situation display.

With the two displays, the NFO is prepared to fire all weapons, other than the cannon and Sidewinders, especially against long-range targets. The pilot can fire any of the aircraft's weapons.

The AWG-9 has extensive built-in test (BIT) features that can isolate a malfunction to one of the 30 boxes comprising the system, identify the decision point where the failure occurred, and advise the crew of the surviving operable AWG-9 modes.

5.1.4 CSDC Subsystem

The CSDC Subsystem performs the aircraft's navigation functions; provides the stabilization interface to the radar, infrared, and missile auxiliary equipment; and handles data flow to the avionic equipment. It includes a Teledyne Systems CP-1050 high-speed digital computer and a multipurpose converter device.

In performing the navigation computations, the CSDC accepts incremental velocity pulses from the Inertial Measurement Unit (IMU) and solves the pure inertial equations. Backup navigation using the Air Data Computer (ADC) and/or the Altitude and Heading Reference System (AHRS) is automatically provided if the IMU fails.

The CSDC also performs extensive onboard checkout (OBC) of the avionics equipment, interfaces with and provides data to the AWG-9 computer, and drives the pilot's Multiple Display Indicator Group (MDIG) and Vertical Display Indicator Group (VDIG).

5.1.5 Acquisition History

The Navy announced that it had awarded a contract to Grumman in January 1969 for a new carrier-based fighter for the U.S. Navy. Known as the VFX during the competition phase of the program, this aircraft was officially designated the F-14 Tomcat.

First flight test of the F-14A prototype took place on 21 December 1970; seven more F-14A's were flying before the end of 1971, and by early 1973, 20 aircraft had logged almost 3000 hours in more than 1500 flights. Weapons System testing accounted for half of the total flight time.

The AWG-9/Phoenix concept was initiated in 1960 and Hughes Aircraft Co. (HAC) was selected as the prime contractor by the Navy in 1962. Flight testing began in 1965, and the first successful intercept was in September 1966. The simultaneous attack capability was demonstrated in March 1969 when two drones were engaged from an F-111B aircraft. Subsequent to cancellation of the F-111B, development of Phoenix has been in relation to the F-14 aircraft. F-14 flight trials started in April 1972, and in December 1972 four jet drone targets were successfully engaged by four Phoenix missiles launched and directed by the AWG-9 System of an F-14A Tomcat.

5.2 COMPUTER SYSTEM ARCHITECTURE

The F-14 aircraft uses two general-purpose computers. The AWG-9 computer is used within the AWG-9 Weapon Control System to perform target tracking, steering, display, computation of missile launch zones and parameters, navigation, and BIT processing. The other general-purpose computer, the CSDC, is used to perform computations for platform management, coordinate transformation, and onboard checkout. The use of these two computers in relationship to the F-14 system interfaces is shown in Fig. 5-1. A summary of the two computers is shown in Table 5-1.

TABLE 5-1

F-14 COMPUTER SUMMARY

Unit	Type	Function	Processor	Memory
C1	CDC 5400B (AWG-9) (24 bit, 1 μs)	Target tracking, steering, display, missile launch zones and parameters, navigation, BIT	1	24k NDRO 8k DRO 140k Tape
C2	Teledyne Systems CP-1050 (CSDC) (20 bit, 7.5 μs)	Platform management, coordinate transformations, avionics input/output, OBC	1	1k NDRO 4k DRO

5.2.1 AWG-9 Computer Subsystem

The AWG-9 computer is a fixed point, twos complement, parallel, programmable general-purpose processor. A 24 bit word length is used although data may be accessed in half-word segments. The instruction list includes 64 whole- and half-word instructions, including multiply, divide, square root, and search instructions. The memory includes 24k of Non-Destructive Read Out (NDRO) and 8k of Destructive Read Out (DRO). The 24k memory may be loaded using the AWM-23 Fleet support equipment but cannot be altered during the flight of the F-14. Special engineering test equipment is used in the test community for memory load, but it is not used in the Fleet. The AWM-23 provides this function for the Fleet. The 8k memory, however, is used for dynamic data and programs loaded from magnetic tape. The memory cycle time is 1 μs, which is also the add and subtract time. Multiply or divide instructions require 11 μs. The central processor is designed to compute in fractional notation in which the binary point is to the left of the most significant bit, rather than to the right of the least significant bit. A magnetic tape unit built into the AWG-9 computer has a capacity of 140k words. Similarly to the NDRO memory, the tape is loaded using the AWM-23 Fleet support equipment and cannot be modified during F-14 flights.

The AWG-9 Computer Interface Unit (IFU) has an extensive capability for interfacing with a variety of F-14 devices. The central processor interface is a parallel Direct Memory Access (DMA) channel to and from DRO memory under IFU control. In addition, a parallel channel to and from the central processor accumulator is available under program control. Serial interfaces include a 10-channel AWG-9 standard serial interface, a 1-channel data link interface, and a 1-channel high PRF missile message interface. An Analog Digital Analog (ADA) converter permits 35 analog inputs and 35 analog outputs to interface with the AWG-9 computer. Parallel digital interfaces include 44 digital inputs and 36 digital outputs. The IFU also includes special features for VCO frequency measurement, NFO display interface, and doppler data conversion.

The AWG-9 computer is a Control Data Corporation (CDC) 5400B computer that was evolved for the AWG-9 from the CDC 5400A. During the F-111 development, a fly-off program for the computer subsystem led to proposals by Honeywell, CDC, and Univac and eventual contract award to CDC. Procurement was driven largely by the requirement for rapid development, which could be most easily accommodated by evolution of the CDC 5400A computer. When the AWG-9 system switched from the F-111 to the F-14, a faster version of the 5400A was developed.

The design approach of the AWG-9 computer subsystem was affected in other ways by the requirement for rapid system development. Because of the tight time constraints in F-14 development, an advanced development model or engineering development model could not be utilized to obtain firm design of the subsystems. In order to minimize hardware changes after deployment of the initial F-14 systems, the design approach for the computer subsystem emphasized flexibility and growth features. The incorporation of traditional radar and system logic functions within the computer subsystem permits design change by the modification of computer programs. Also many interfaces were designed to be fully programmable to maximize flexibility in interfacing with other subsystems. Implementation of functions in the computer subsystem was also performed, where possible, to minimize hardware development. This has led to expanded interaction in control of the system hardware functions by the computer subsystem. Radar control loops are closed through the computer subsystem, resulting in a requirement for highly efficient and responsive computer software design. To improve computer processing resources, the memory cycle time was shortened, processor logic was speeded up, and the DMA interface channel was expanded.

Reliability figures for the computer subsystem have been obtained from operations at NAS Miramar and the USS Enterprise. Of the 22 hr MTBF required of the AWG-9 system, 12% is allocated to the computer subsystem (equivalent to 184 hr). In about 2000 hours of operations at NAS Miramar, the computer subsystem experienced 494 hr of MTBF, which is 265% of the objective. In about 2000 hours of operations from the USS Enterprise a 113-hr MTBF or 62% of the objective was obtained for the computer subsystem. However, about 50% of the failures were associated with the single component type in the computer interface hardware conversion (A/D and D/A) unit.

5.2.2 CSDC Computer Subsystem

The Computer Signal Data Converter (CSDC), developed by Grumman Aerospace Corporation, includes a number of I/O conversion interface modules and a GP computer as shown in Fig. 5-2. The CP-1050 computer, procured under contract to Teledyne Systems, was evolved from a computer used in previous systems. The processor has an add time of about 7 μs and a multiply time of 31 μs. A 20 bit word length is used with a 4k DRO memory and a 1k NDRO memory.

To initially select a signal data converter unit, requirements were defined and proposals obtained, all but one of which specified electromechanical devices. The Teledyne proposal included a GP computer and was selected based on a combination of cost, volume, MTBF, and growth potential.

The CSDC performs primary navigation including platform maintenance, avionics on-board checkout, converter and conversion functions, central interface for all avionics, partial display interface, data link interface, and platform alignment.

5.3 COMPUTER PROGRAM ARCHITECTURE

5.3.1 AWG-9 Program Architecture

To implement its assigned functions, a program architecture has been established specifically for the AWG-9 Weapon Control System with strong consideration for efficiency of memory and time utilization. As mentioned in Section 5.2., the AWG-9 computer is highly involved in the radar control loop requiring efficient and responsive program execution. The program is entirely interrupt-driven eliminating the need for any general-purpose scheduling with the Executive. The program is not modular, but rather contains a series of over 100 routines that are executed in particular sequences for each function required. The routines for each function are indicated in Fig. 5-3.

Basic timing for the program interrupts is generated from an 8 ms radar interrupt. Each 8 ms the critical radar data is processed. A variety of other functions are processed at slower periodic rates, which the executive schedules when all 8 ms radar processing is complete. An overview of this architectural structure is shown in Fig. 5-4.

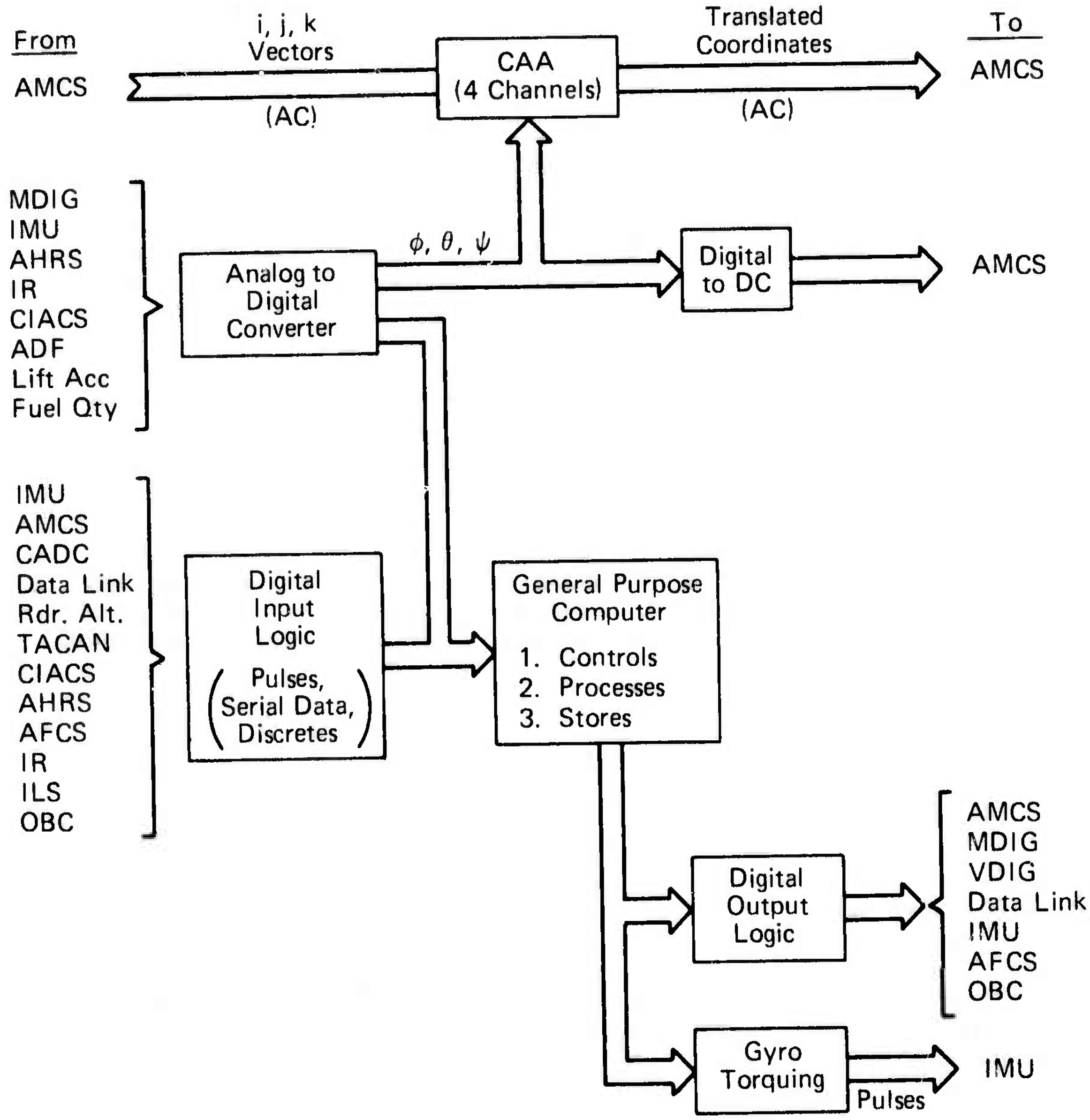


Fig. 5-2 CSDC Block Diagram

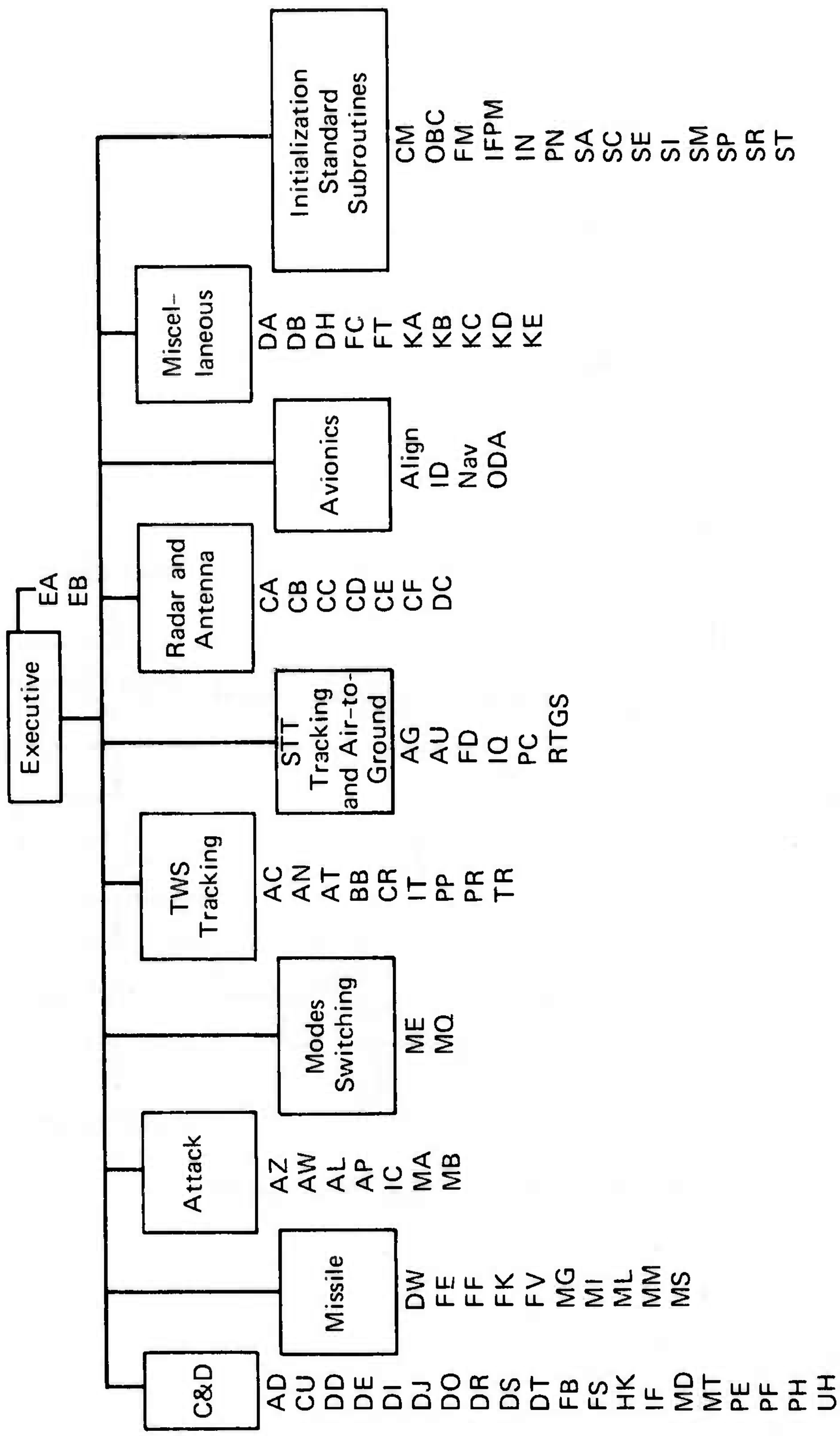


Fig. 5-3 Program Modules versus Tactical Routines (from Hughes)

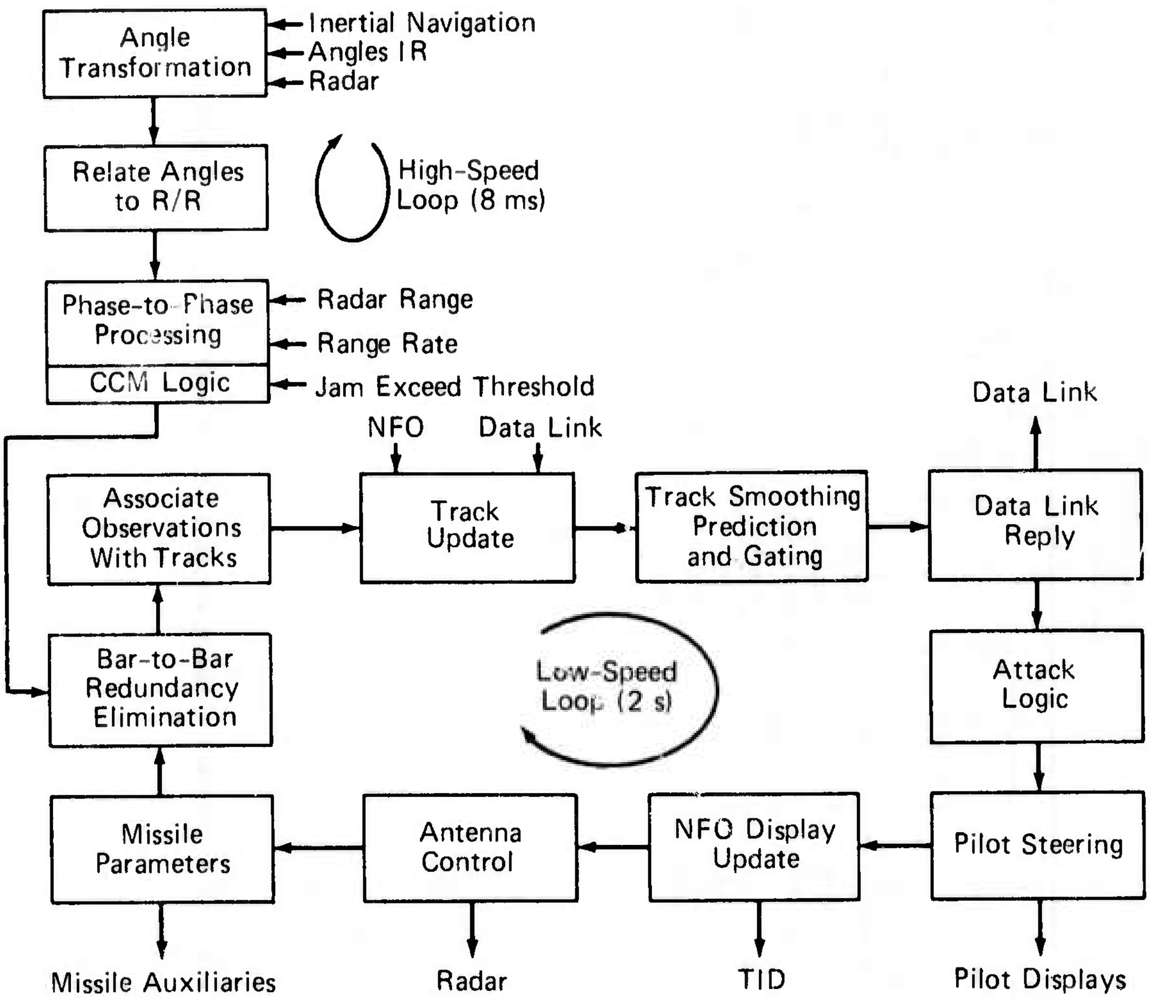


Fig. 5-4 Architectural Structure Overview (from Hughes)

Recovery from computer program aborts can be done by reinitialization of the computer program and by reload from the magnetic tape. Since 24k of the 32k memory is NDRO, only the 8k memory must be reloaded. Although there is only one computer involved in the AWG-9 system, a major hardware failure within the computer system is required to abort the mission. Replacement of the computer modules is performed on the aircraft carrier or on the land-based site.

5.3.2 AWG-9 Program Functions

The program functions within the AWG-9 computer are subdivided into tactical and BIT as shown in Fig. 5-5. The relative sizes of each of the tactical functions are illustrated in Fig. 5-6. Note that of the 39k tactical words (orders), a required 15k are resident on tape. The tape also includes 50k words for BIT. These functions are summarized as follows:

5.3.2.1 Tactical Programs

Controls and Displays

Displays Symbolic Target and Ownship Data in Two Orientations

Provides Data Entry, Data Entry, Data Readout, and Mode Selections

4500 Orders, 11%

Missile

Provides Launch Zone and Missile Parameter Data

2400 Orders, 6.5%

Attack

Assigns Target Priorities and Weighting for Launch Logic

3800 Orders, 9.5%

Modes Switching

Provides Timing and Logical Changes for System Modes

500 Orders, 1.5%

TWS Tracking

Correlation of Observations to Establish and Update Multiple Target Tracks

3200 Orders, 8%

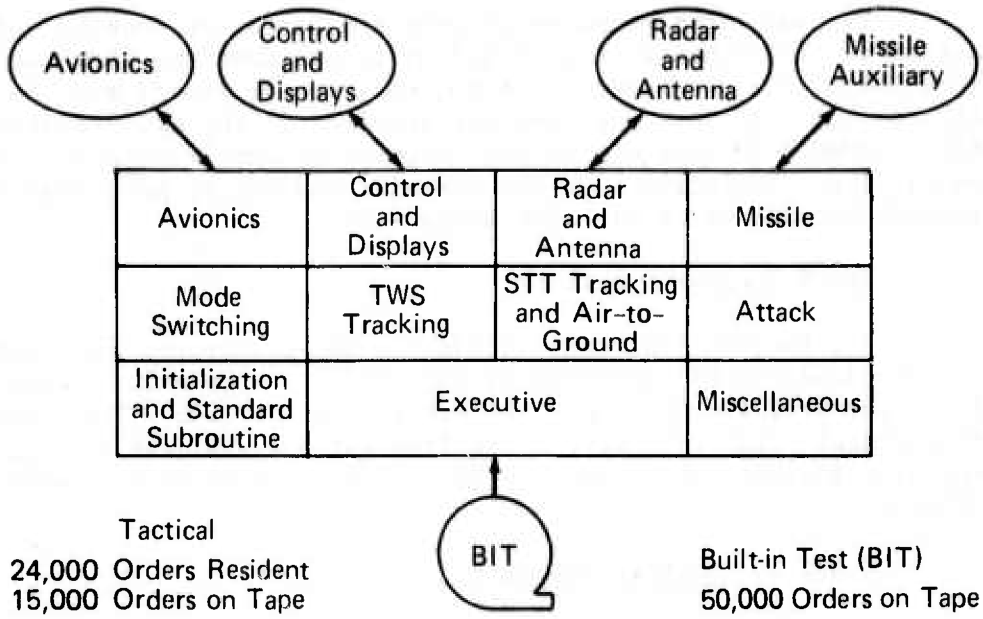


Fig. 5-5 AWG-9 Program Module Functions (from Hughes)

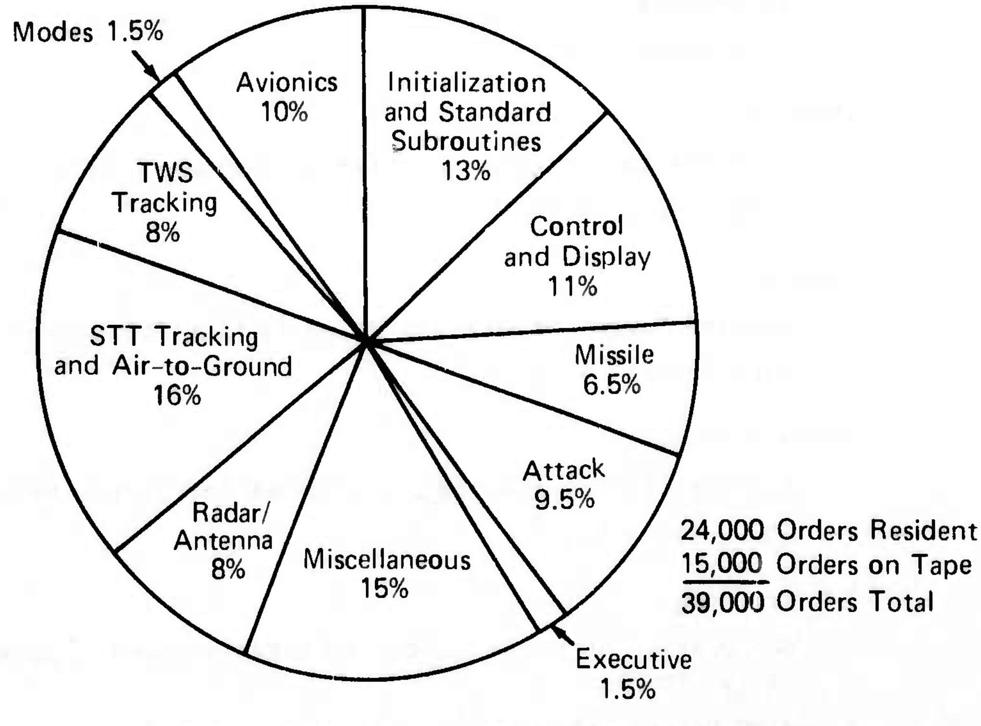


Fig. 5-6 AWG-9 Program Module Size (from Hughes)

STT Tracking and Air-to-Ground

Provides Angle and Rate Tracking, A/A Processing, and Gun Mode Aids

1975 Orders, (plus 4250 on tape), 16%

Radar/Antenna

Provides Clutter and Acquisition Processing

Controls the Antenna Pattern and Position

3300 Orders, 8%

Avionics

Provides Navigation and Alignment Processing

1350 Orders (plus 3850 on tape), 10%

Miscellaneous

Instrumentation, In-Flight-Training, and Data-Link Function

0 Orders (plus 5000 on tape), 15%

Initialization and Standard Subroutines

Initialization and Power Sequencing Functions

Bulk Store Transfer and Software Monitoring Processing

2900 Orders (plus 1900 on tape), 13%

Executive

Timing, Control, and Interrupt Processing

650 Orders, 1.5%

The various routines (approximately 100) associated with each of the above tasks are listed in Fig. 5-3.

5.3.2.2 Built-In Test Programs

In addition to the tactical functions, a number of BIT functions are defined as follows:

C&D

Drives the C&D with Test Patterns

750 Orders, 2%

CP,IFU

Exercises the Timing and Control Functions

Tests the Memories and Instruction Set

10,000 Orders, 20%

Radar

Performs a Confidence Test of the Entire Radar Loop

Prompts the Operator to the Correct Fault Isolation Test

9000 Orders, 18%

Missile

Determines Missile Readiness Status

7500 Orders, 15%

Fault Isolation

Provides Fault Isolation for the Following Functions:

Receiver:	4250 Orders, 8%
Transmitter:	3500 Orders, 7%
Antenna:	4500 Orders, 9%
STT Loop:	4500 Orders, 9%

Special Tests

Special Testing of Subsystem Interfaces, Missiles, and Power

4000 Orders, 8%

Displays and Executive

Degraded Mode Assessment, WRA Display, and Test Decision Points for Analysis

2000 Orders, 4%

The relative memory usage for the BIT functions indicated above is shown in Fig. 5-7.

5.3.3 CSDC Program Architecture

The program used in the CSDC is a special-purpose program tailored for the F-14 functions. The software system main driving loop is represented by Fig. 5-8, which shows that the Executive is essentially distributed throughout the application program.

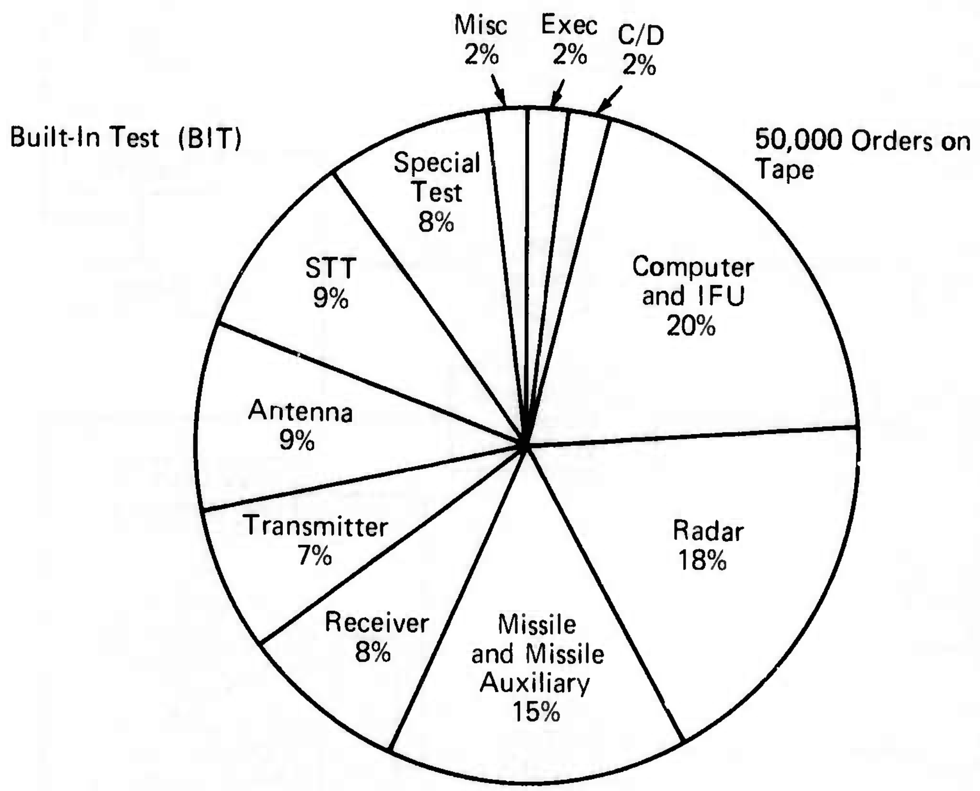


Fig. 5-7 Relative Memory Usage for AWG-9 Diagnostic and Test Software (from Hughes)

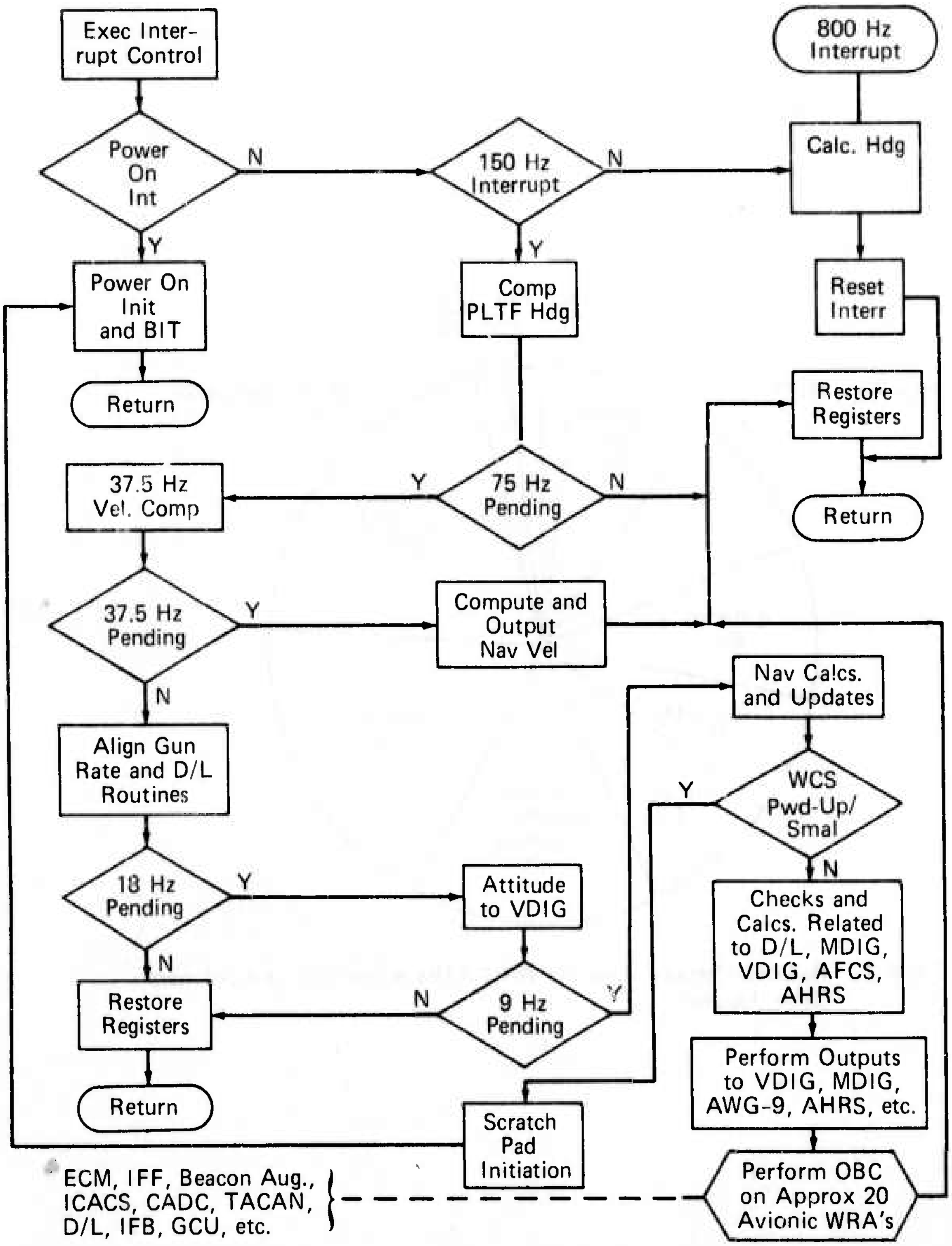


Fig. 5-8 Main Driving Loop for CSDC Computer Program

5.3.4 CSDC Program Functions

The functions of the CSDC computer program are as follows:

1. Tactical Functions

   Navigation: Primary navigation, including platform maintenance.

   Converter Functions: Software Controlled multiplexing of A/D, D/A, and CAA conversions.

   Controls: Uses or transfers more than 100 discretes and is the central interface for all avionics.

   Displays: Interfaces with MDIG and VDIG, supplying all MDIG avionic inputs and many of the VDIG inputs.

   Data Link: Inputs, decodes, and replies to the data link subsystem.

   Alignment: Alignment procedure of the IMU platform.

2. Test Functions

   Onboard Checkout: Avionics go-no-go indications (includes continuous self-test).

5.4 SOFTWARE DEFINITION, DESIGN, AND IMPLEMENTATION

5.4.1 AWG-9 Program Definition

An overview of the definition documents for the AWG-9 system is shown in Fig. 5-9. The following documents define the AWG-9 system requirements and software:

1. Contract Specifications (AS2195, AS2197, AS2206, etc.): A group of approximately 17 specifications covering AWG-9 system performance. There are no specific software performance criteria except in terms of system performance. These documents serve the purpose of the Computer Program Peformance Specifications;

2. HAC Software Design Requirement Drawings (481CPN/B-600): A group of drawings used in early phases of development of the program to convey to the programming activity the specific requirement for developing the program. These drawings were

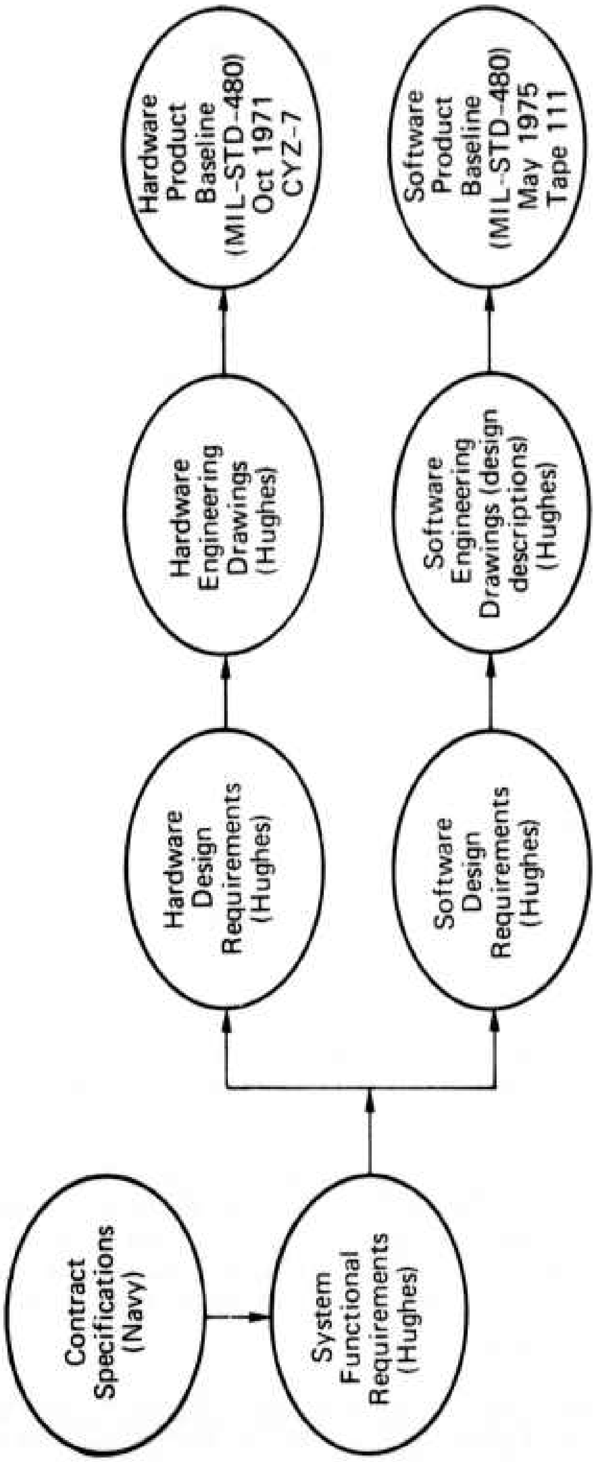


Fig. 5-9 AWG-9 Design Development Documents (from Hughes)

not updated after initial design to reflect system changes. This document corresponds to the Computer Program Design Specifications;

3. HAC Software Design Description Drawings (4810CP-700): A group of drawings containing narrative and flow chart descriptions of the various computer program components, i.e., routines, subroutines, BIT sequences, software dictionary items, and standard subroutines. Generation of these documents including flow chart generation is fully automated. These documents correspond to the Computer Sub-Program Design Documents. (The dictionary defines all common terms and equations used throughout the program. Standard subroutines are those items used by more than one routine in the computer program.);

4. Computer Program Package: The computer program package consists of programs on magnetic tapes and program listings; and

5. Phoenix XN-3 Computer Programming Policies and Procedures: The document was initially used during the initial development in 1969 but is not currently maintained. It consisted of two sections defining program development steps and program development policies. Included in the first section were definitions for the functional design document, flow charting, scaling, coding, static simulation, dynamic simulation, and the program description document. Included in the second section, program development policies, were definitions for tape identification, computer program routine all letter allocation, labelling, comments, subroutine calling sequence, mode transitions, memory utilization, and symbology indentation control.

5.4.2 AWG-9 Program Design

Initial design was aided by early developmental work performed at the Naval Air Development Center (NADC), particularly in the area of track-while-scan radar logic. Later involvement by NADC in design review and interaction also proved useful in the design activity.

The design document for AWG-9 software consists of a series of documents entitled HAC Software Design Description Drawings (4810CP-700 drawings). These documents went under MIL-STD-480 control as of May 1975. As an example of the level of detail in these documents and the automatic generation of text and flow charts, three sample pages of an 18-page document for the Data Entry Routine are shown in Figs. 5-10 through 5-12.

04/22/75 AUTOFLOW CHART SET - PHX PAGE 02

CHART TITLE - DE - DATA ENTRY ROUTINE (U) - 3238368 - REV K

PURPOSE

(U) THE PURPOSE OF THIS ROUTINE IS TO ENTER DATA INTO THE APPROPRIATE LOCATION WHENEVER THE NFO ENTERS DATA ON THE COMPUTER ADDRESS PANEL (CAP).

FUNCTIONAL DESCRIPTION

INTRODUCTION (U) THE DATA ENTRY (DE) ROUTINE IS ENTERED FROM THE FUNCTION SWITCH (FS) ROUTINE DURING THE 8 MSEC CYCLE BY PRESSING THE ENTER BUTTON ON THE CAP. THE CATEGORY SWITCH SETTING, FUNCTION SWITCH SELECTION, KEYBOARD FUNCTION CODE AND THE TYPE OF HOOK PRESENTLY IN EFFECT ARE EXAMINED TO DETERMINE THE TYPE OF DATA BEING ENTERED. THE DATA IS CONVERTED TO BINARY, PROPERLY SCALED AND STORED IN THE APPROPRIATE LOCATION FOR USE BY THE PROGRAM.

DESCRIPTION (U) THE DE ROUTINE FIRST CHECKS THE STATUS OF THE KEYBOARD FUNCTION. IF AN ILLEGAL KEYBOARD FUNCTION IS ENTERED, THE ROUTINE EXITS. OTHERWISE, THE DE ROUTINE CALLS THE DIGITAL INPUT (DI) ROUTINE WHICH CONVERTS AND SCALES THIS INPUT DATA.

(U) THE CATEGORY AND KEYBOARD FUNCTION FLAGS, WHICH ARE SET BY DI, DETERMINE THE LOCATIONS WHERE THE SCALED DATA IS TO BE STORED.

(U) THE DE ROUTINE THEN CHECKS IF A HOOK IS IN EFFECT. IF A PSEUDO HOOK IS IN EFFECT, LATITUDE AND LONGITUDE ARE STORED IN TEMPORARY LOCATIONS, FROM WHICH CONVERSIONS OF THE EAST AND NORTH TARGET RANGE VECTOR COMPONENTS ARE MADE.

(U) ENTRY OF EITHER LATITUDE OR LONGITUDE CAUSES CALCULATION AND STORING OF RANGE INFORMATION. CONSEQUENTLY, THE STORED VALUE OF LATITUDE OR LONGITUDE RESULTS IN AN INCORRECT CALCULATION OF RANGE AND BEARING UNTIL THE SECOND VALUE IS ENTERED.

(U) CALCULATION OF LATITUDE AND LONGITUDE FROM RANGE AND BEARING IS PERFORMED IN THE SAME MANNER. RANGE AND BEARING ARE STORED IN TEMPORARY LOCATIONS PRIOR TO CONVERSION TO LATITUDE AND LONGITUDE. ENTRY OF EITHER QUANTITY CAUSES CALCULATION AND STORING OF LATITUDE AND LONGITUDE. CONSEQUENTLY, THE STORED VALUE OF RANGE OR BEARING WILL USUALLY RESULT IN AN INCORRECT CALCULATION OF LATITUDE AND LONGITUDE UNTIL THE SECOND VALUE IS ENTERED.

(U) FOR PSEUDO FILES, THE TARGET X AND Y COORDINATES ARE ALSO CALCULATED WHENEVER RANGE, BEARING, LATITUDE, OR LONGITUDE IS ENTERED.

(U) WHEN HEADING, SPEED, OR RANGE IS ENTERED INTO A SENSOR FILE, IT IS STORED INTO THE APPROPRIATE LOCATION AND RANGE RATE VALID IS RESET AND THE ASPECT ANGLE FILTER IS INITIALIZED. ALSO, WHEN RANGE IS ENTERED THE KALMAN FILTER IS INITIALIZED.

(U) IN THE NAV CATEGORY, WHEN THE OWN A/C FLAG IS ON, THE DE ROUTINE STORES ENTRIES OF LATITUDE, LONGITUDE, HEADING,

Fig. 5-10 Autoflow Chart Set, Data Entry Routine, Page 2

04/22/75 AUTOFLOW CHART SET - PHX PAGE 03

CHART TITLE - OE - OATA ENTRY ROUTINE (U) - 3238368 - REV K

AND ALTITUDE OF OWN A C INTO LOCATIONS OUTSIOE THE TRACK
FILE FOR USE BY THE NAVIGATION ROUTINE

(U) WHEN THE NAVIGATION SYSTEM IS IN AN ALIGNMENT MODE, HEADING, COURSE AND BEARING ARE TRUE NORTH REFERENCED
OTHERWISE, THEY ARE MAGNETIC NORTH REFERENCED AND THE MAGNETIC VARIATION IS ADDEO TO THE KEYBOARD VALUE BEFORE
DE STORES THE ENTRY

(U) THE ATTACHED TABLE NO 1 SPECIFIES THE OATA ENTRIES ALLOWED AND DATA READOUTS EXPECTED BASED ON TYPE OF HOOK
IN EFFECT

Fig. 5-11 Autoflow Chart Set, Data Entry Routine, Page 3

04/22/75 AUTOFLOW CHART SET - PHX PAGE 06

CHART TITLE - DE - DATA ENTRY ROUTINE (U) - 3238368 - REV K

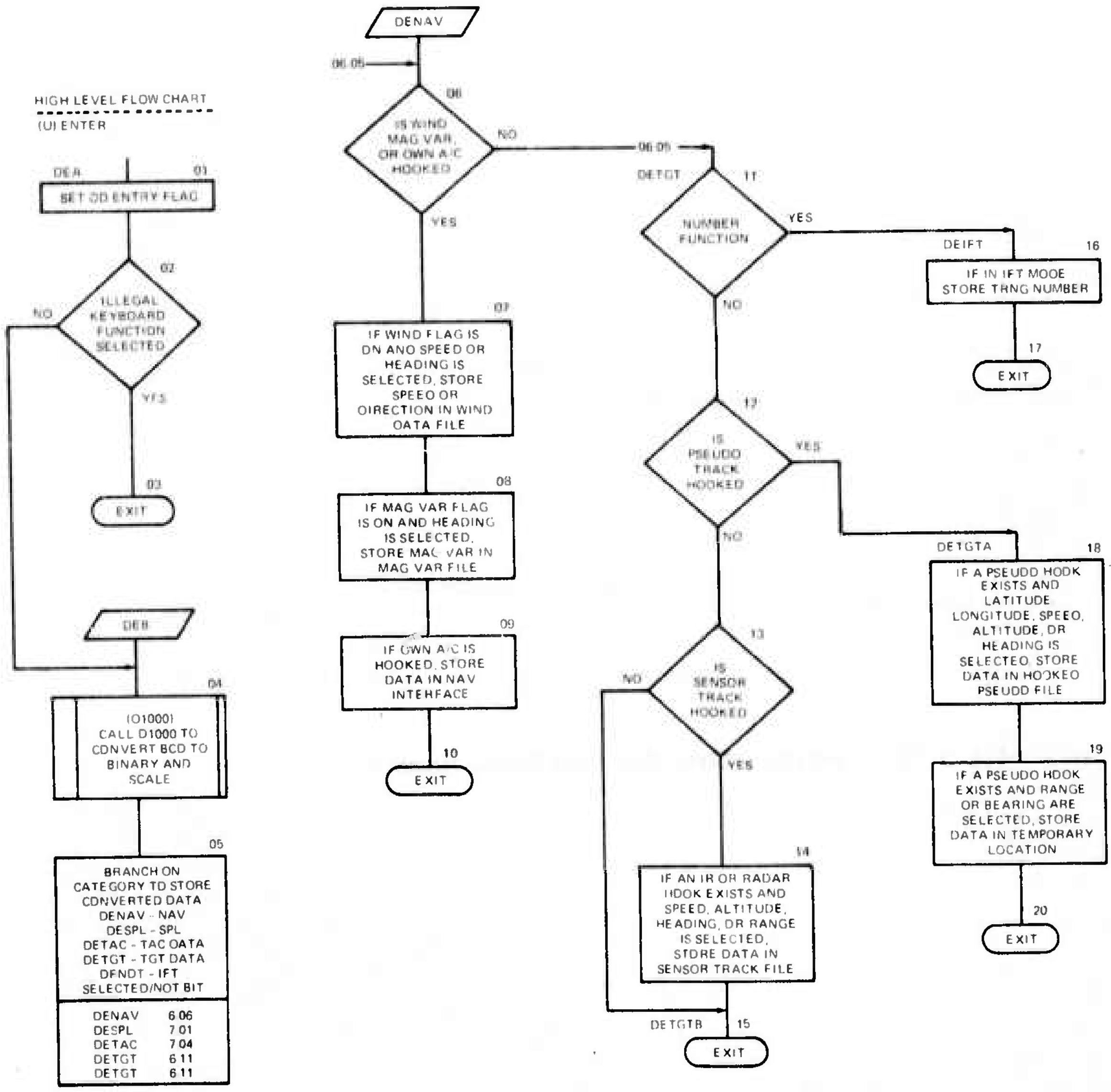


Fig. 5-12 Autoflow Chart Set, Data Entry Routine, Page 6

5.4.3 AWG-9 Program Implementation

Figure 5-13 illustrates the development cycle used in software generation for the AWG-9 system. In particular, the tasks required for computer programming are illustrated in Fig. 5-14.

5.4.3.1 Initial Development

Since the software for the AWG-9 was developed prior to an available system to exercise the computer system, extensive use of simulation was required in program development. Figure 5-15 illustrates the computer-based systems for computer program development. Prior to operational program coding, extensive parametric analysis was performed, which formed the basis for simulations later used in performance evaluation. Simulations were performed for such functions as track-while-scan, velocity loop, angle tracking loop, low PRF range tracker, and F-14 realtime steering.

5.4.3.2 Languages and Compilers

The Metaplan language was selected in 1965 as the language for use in the AWG-9 Weapon System. At the time, there was no standard or convenient high-level language available for avionic systems. An initial requirement was for machine independence so that programs could be developed prior to the selection of the computer to be used for the system. Metaplan was originally a systems implementation language developed for use in writing operating systems programs. The compiler for the AWG-9 system was developed by a subcontractor to Hughes Aircraft and later development and maintenance was continued by Hughes. One of the prime goals in the design of the compiler was efficiency of code generation, which was required by avionics programs. In three benchmark programs, an efficiency of between 90 and 95% of an assembly language program was demonstrated. An assembler is also available for the AWG-9 computer that can be used for code segments that must be extremely efficient.

5.4.4 CSDC Program Definition

Since the CSDC software program is only a small part of the system as compared to the total F-14 aircraft, Grumman has not invested a great deal of effort in the software definition. It appears to have been a one-man effort based on a general outline of the functions to be performed by the computer. (Note: the major software effort in the F-14 program is tied up with the AWG-9 Weapon System.)

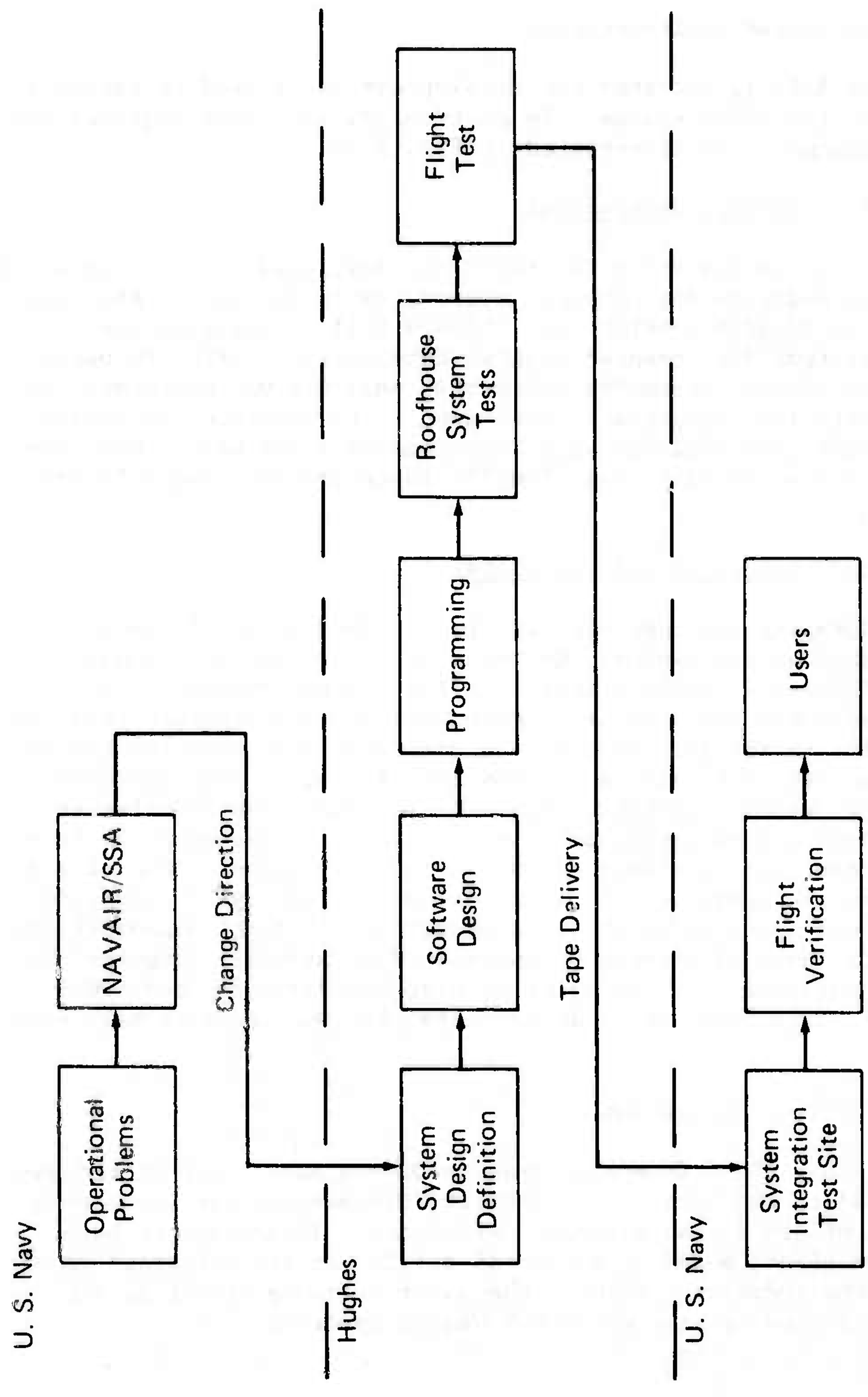


Fig. 5-13 AWG-9 Software Development Cycle (from Hughes)

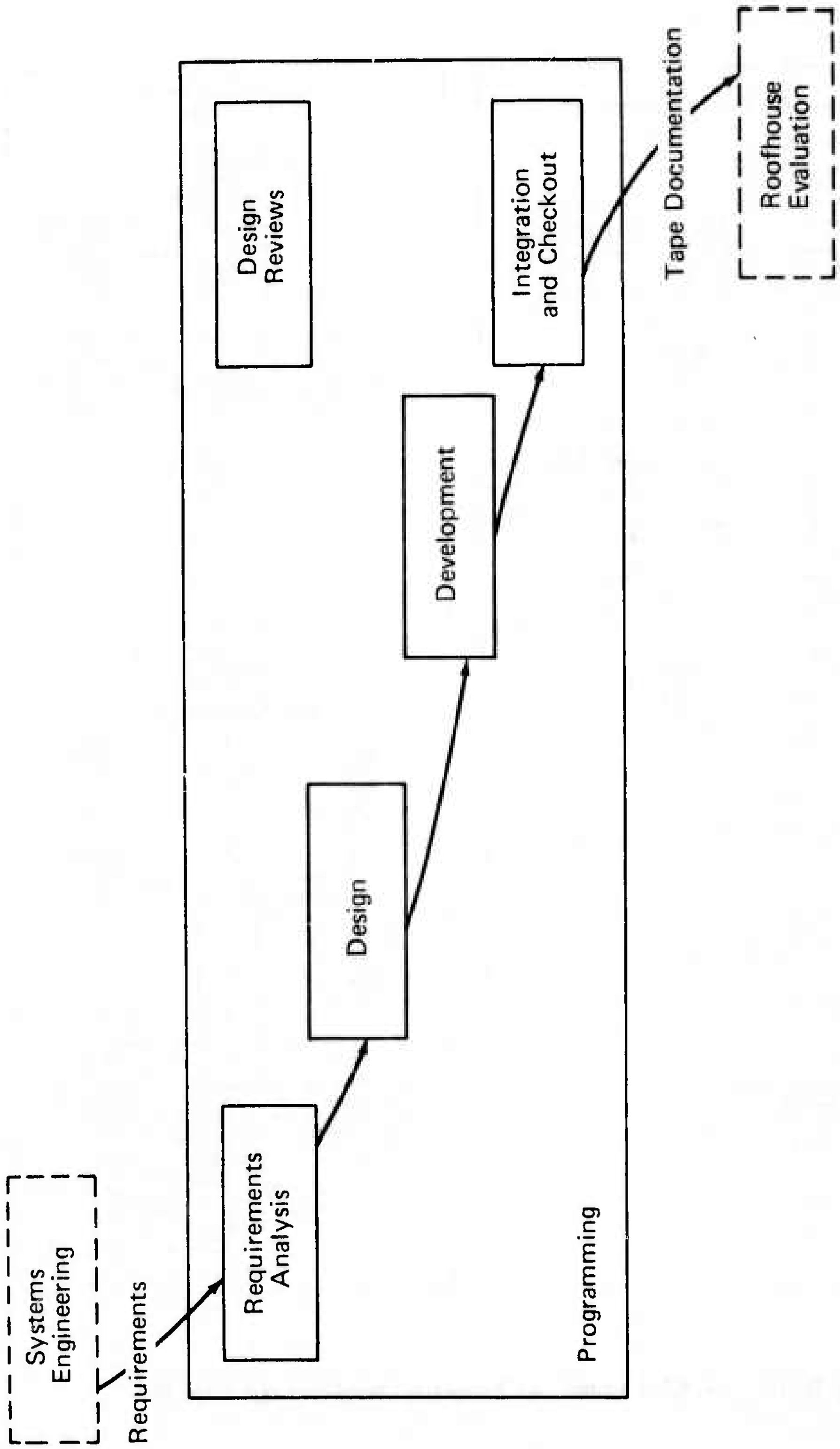
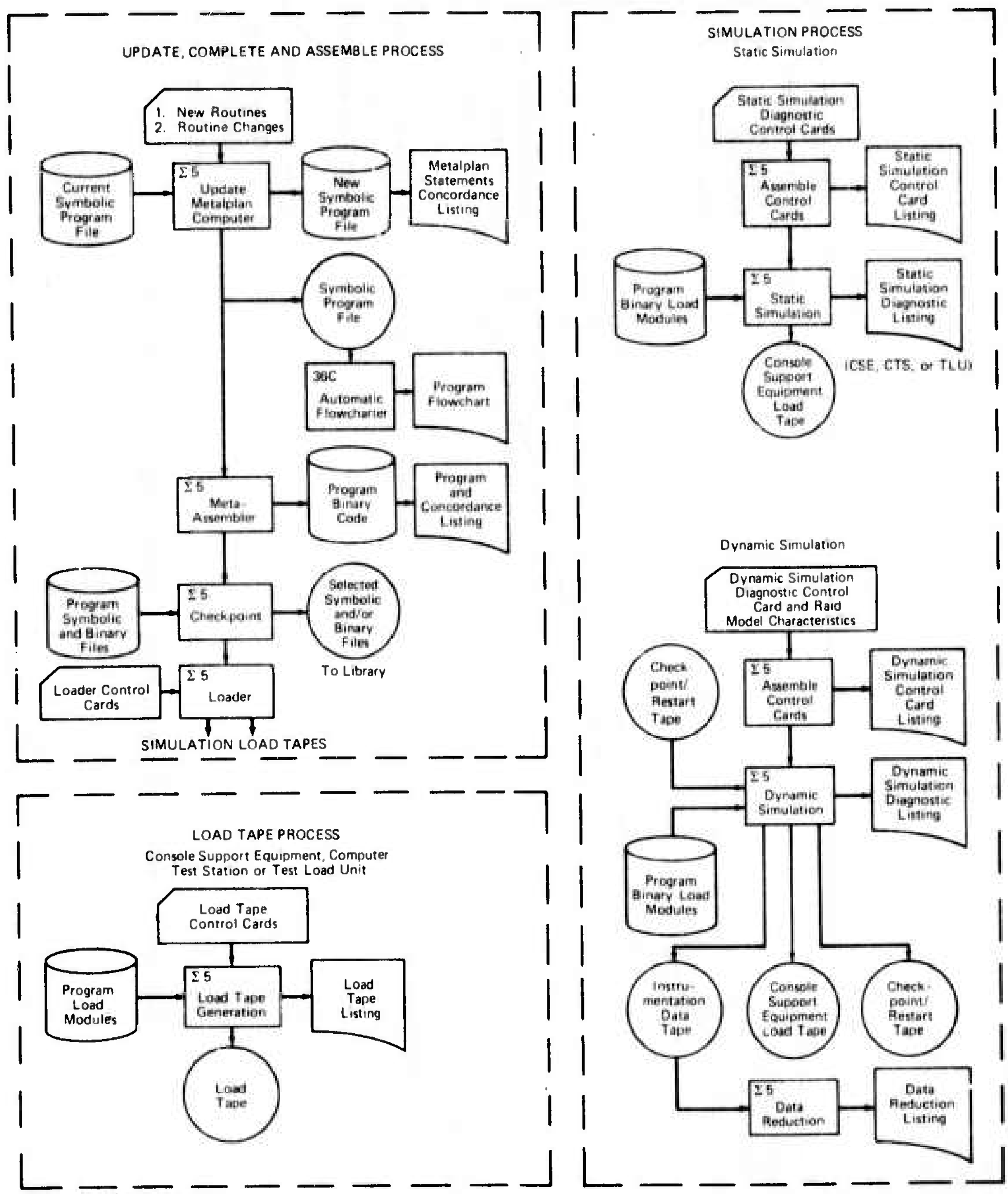


Fig. 5-14 AWG-9 Programming — Major Tasks (from Hughes)



Σ 5 = Sigma 5 Computer

Fig. 5-15 AWG-9 Computer Program Development Process

5.4.5 CSDC Program Design Documents

The following documents contain a description of the program design for the purpose of system maintenance and operational training and procedures. However, they do not discuss the methods used to design the program itself.

1. Technical Manual Organizational Maintenance Integrated Weapon System Functional Diagrams; NAVAIR01-F14AAA2-2-16.

2. Navy Aviation Training and Operational Procedures Standards (NATOPS).

5.4.6 CSDC Program Implementation

No formal procedures were followed in implementing individual software modules (see Section 5.4.4). However, all software was thoroughly tested on the total system level in the System Integration Test Site (SITS) (see Section 5.5.3).

5.5 SOFTWARE VALIDATION AND INTEGRATION

Operational F-14/Phoenix programs are tested at the total system (hardware and software) level. Programs are run in real time in an AWG-9/CSDC computer system that is interfaced with the radar, display, and missile interface subsystem. Test results are measured against a baseline or increased system performance models depending on specific changes. Within Hughes Aircraft Company (HAC), test and validation is performed at the system engineering and flight test levels. Validated programs are then delivered to the Navy and Grumman Aerospace Corporation (GAC) for system validation before deployment in the Fleet.

5.5.1 AWG-9/HAC Test and Validation

Validation tools in use by HAC include a Sigma-5 based simulation system as depicted in Fig. 5-16, and various roofhouse and flight test tools. The roofhouse at HAC includes two AWG-9 systems into which a number of simulated inputs can be made including a moving target simulator, an IF radar target simulator, and an ECM pod. Aircraft flyovers are also used in the software validation. Computer support equipment is available for detailed program analysis and debugging. Equipment used during HAC flight tests at the Pacific Missile Range include two bailed aircraft (TA3-B, F-14), targets supplied by PMR, missiles for captive carry, and missiles for launch. During all tests, data recordings can be made on magnetic tape of intermediate and interface variables. The Hughes Phoenix roofhouse offers a unique and diversified resource for development of the AWG-9 software. In the roofhouse, the software is

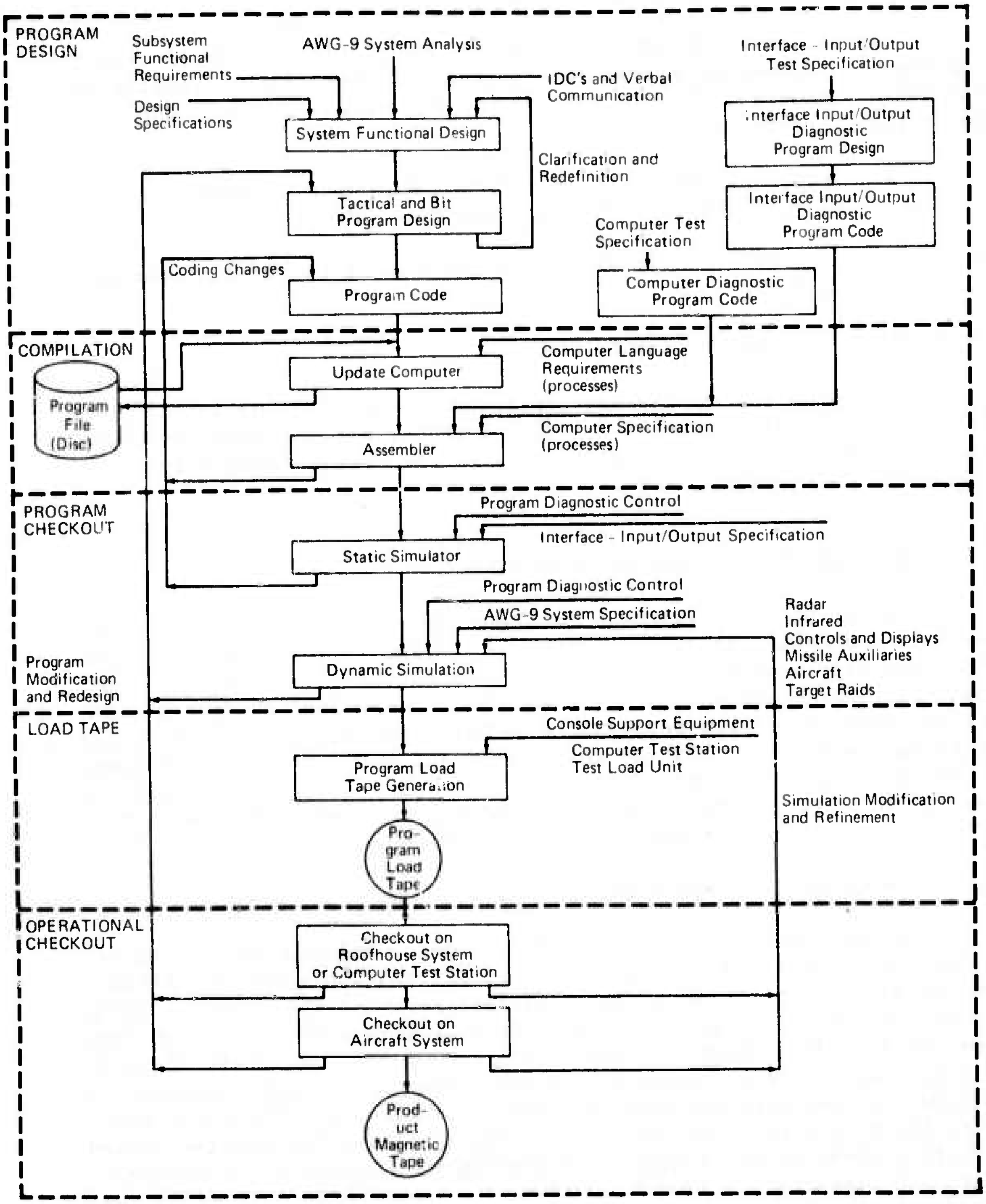


Fig. 5-16 Validation of AWG-9 Tactical Programs

combined with the AWG-9 hardware, including an AIM-54 missile, to form the total AWG-9 hardware, including an AIM-54 missile, to form the total AWG-9 system. This combination of the hardware and software plus the totality of target/hardware/missile simulators and instrumentation/recording equipment makes the roofhouse an invaluable resource for two vital phases of software development, software checkout, and software verification/evaluation.

The roofhouse checkout phase of software development deals with individual software changes. The roofhouse with its available equipment thus allows the software engineer to determine if a particular software change has been implemented correctly and if it accomplishes the desired function without impacting other software in a detrimental manner.

The software verification/evaluation phase of software development ascertains the overall performance of the complete software package with regard to system design requirements, performance specifications, system threats/missions, and agreements between the customer and contractor. This phase is accomplished by the software test engineer designing tests for the above mentioned conditions and then either using the various simulators to input the required signals or using the roofhouse capability of having real targets fly against the system. The roofhouse is an ideal source for the performance of these tests since the instrumentation/recording equipment it contains allows the software test engineer to capture quickly all necessary information.

With use of PMR radars and missile range computers, AWG-9 data and ground data are merged to develop accuracy data used in determining acceptability. The decision for a formal tape release of an AWG-9 program is made at a formal management review in which HAC System Engineering presents the results of verification testing. Results include testing accomplished, planned testing, tests to be accomplished, performance demonstrated, and problems to be fixed. When a "release" decision is made, the tape and documentation are delivered to the Navy Software Support Activity (SSA) for tests.

5.5.2 CSDC/Grumman Test and Validation

Since program changes in the CSDC computer are generally highly visible, Grumman's approach to validation and testing of development software relies on use of the SITS (a Grumman developed test tool) as depicted in Fig. 5-17. Validation of Grumman-developed AWG-9 computer resident programs proceeds generally as outlined in the previous section.

5.5.3 F-14 System Test and Validation

Further testing on delivered programs was performed at PMR Pt. Mugu by Grumman in the SITS. Figure 5-18 illustrates the components of

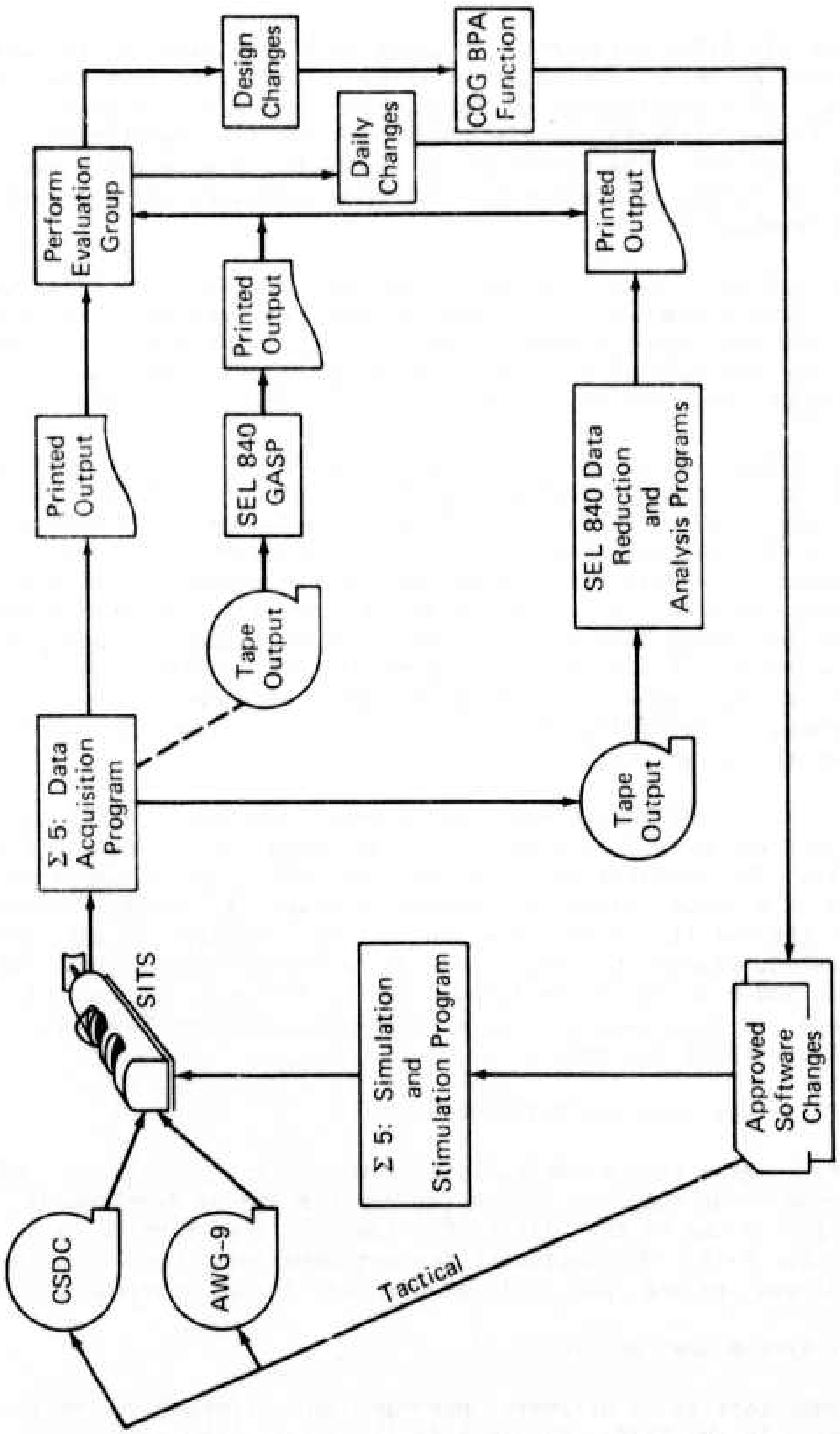


Fig. 5-17 **SITS Testing of Development Software**

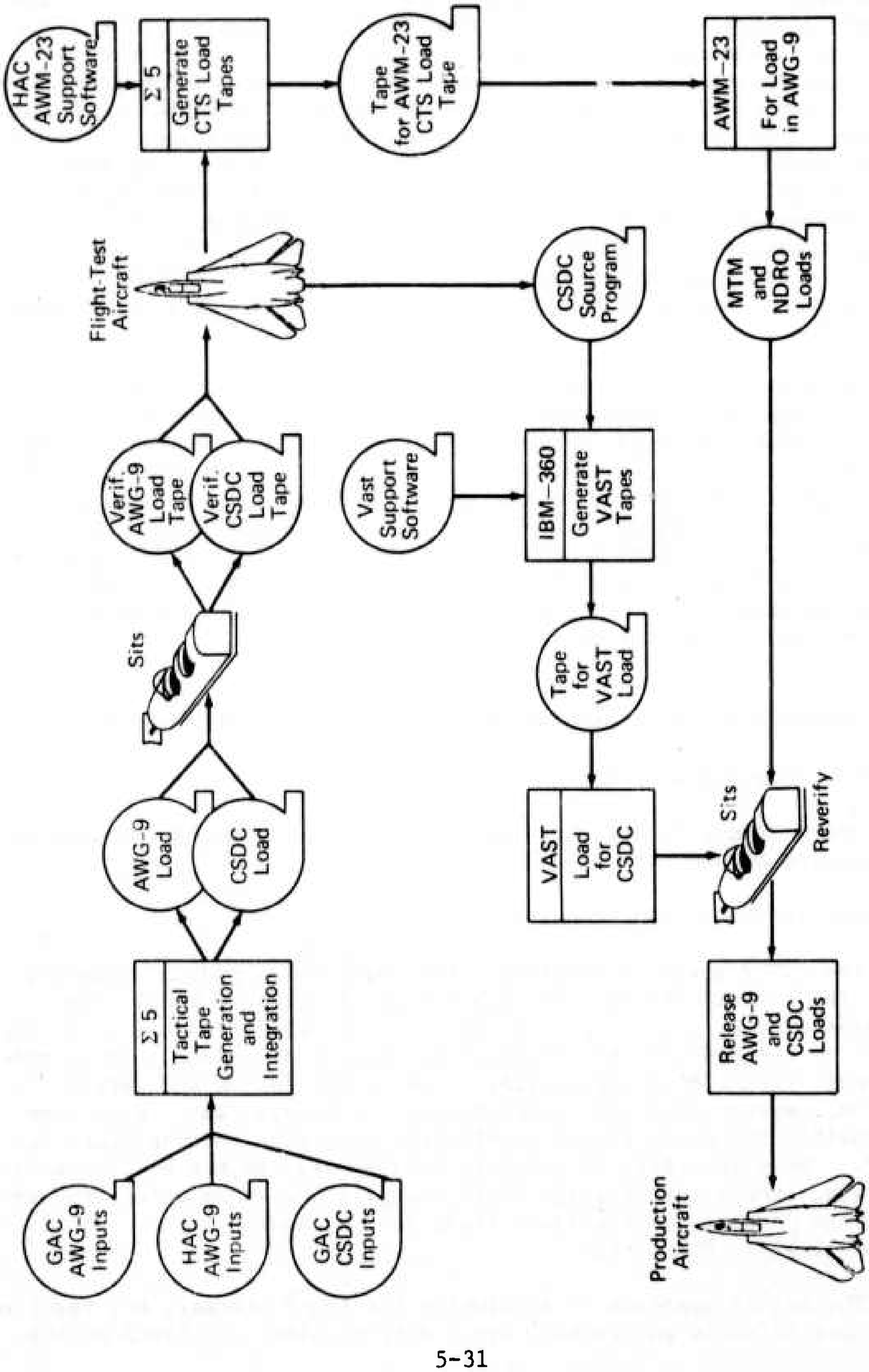


Fig. 5-18 SITS Testing of Production Software

the test site when used to test production software. SITS is a Grumman-developed software development tool that includes a replica of the F-14A forward module housing all weapon system hardware. It has now been transitioned to the Navy SSA. An associated computer complex provides controlled inputs of synthetic targets and dynamic simulation of flight parameters. SITS provides step-by-step buildup, integration, and evaluation of weapon system hardware and software while permitting full crew participation. SITS supporting facilities permit acquisition of desired performance data and data reduction for subsequent system analysis. The test site is used by the SSA to evaluate and verify tactical tapes before delivery to the Fleet. It is also used to evaluate and verify hardware changes to weapon systems before production and/or Fleet incorporation.

In addition to its use in test and validation, the test site provided a significant contribution in the test of the Link 4A two-way data link. Since the F-14 is the only aircraft with a two-way Link 4A, the system for testing the Link 4A hardware had not been developed. A Sigma-5 computer was used to control a Link 4A transmitter for simulation of a participating unit. F-14 hardware was then tested with the simulator. Later the Link 4A was tested with NTDS using FCDSSA programs at PMR and the F-14 at the test site. Compatibility with NTDS was established in about 1972. Later integration of the E-2C to provide F-14 to E-2C two-way communication was tested.

5.6 SOFTWARE ACQUISITION MANAGEMENT ORGANIZATION AND METHODS

5.6.1 HAC Management Organization

The software management organization at HAC and its relation to other agencies is shown in Fig. 5-19.

5.6.2 HAC Personnel Management

The AWG-9 software management process uses a "module" concept; that is, the software is divided into several functional modules to which teams of specialists are assigned. The module teams are under the direction of the AWG-9 System Engineering Department. Each team is made up of people from system engineering (both system design and system evaluation), system analysis, programming, and flight test. Each team is responsible for its assigned module from inception through Fleet deployment. The three tactical software modules are the track-while-scan (TWS) group, single-target-track (STT) group, and weapons group; the two BIT software modules are the radar group and processing group. The five teams are shown in Fig. 5-20.

The module approach to developing the AWG-9 software has resulted in efficient software generation, since many problems are found at the

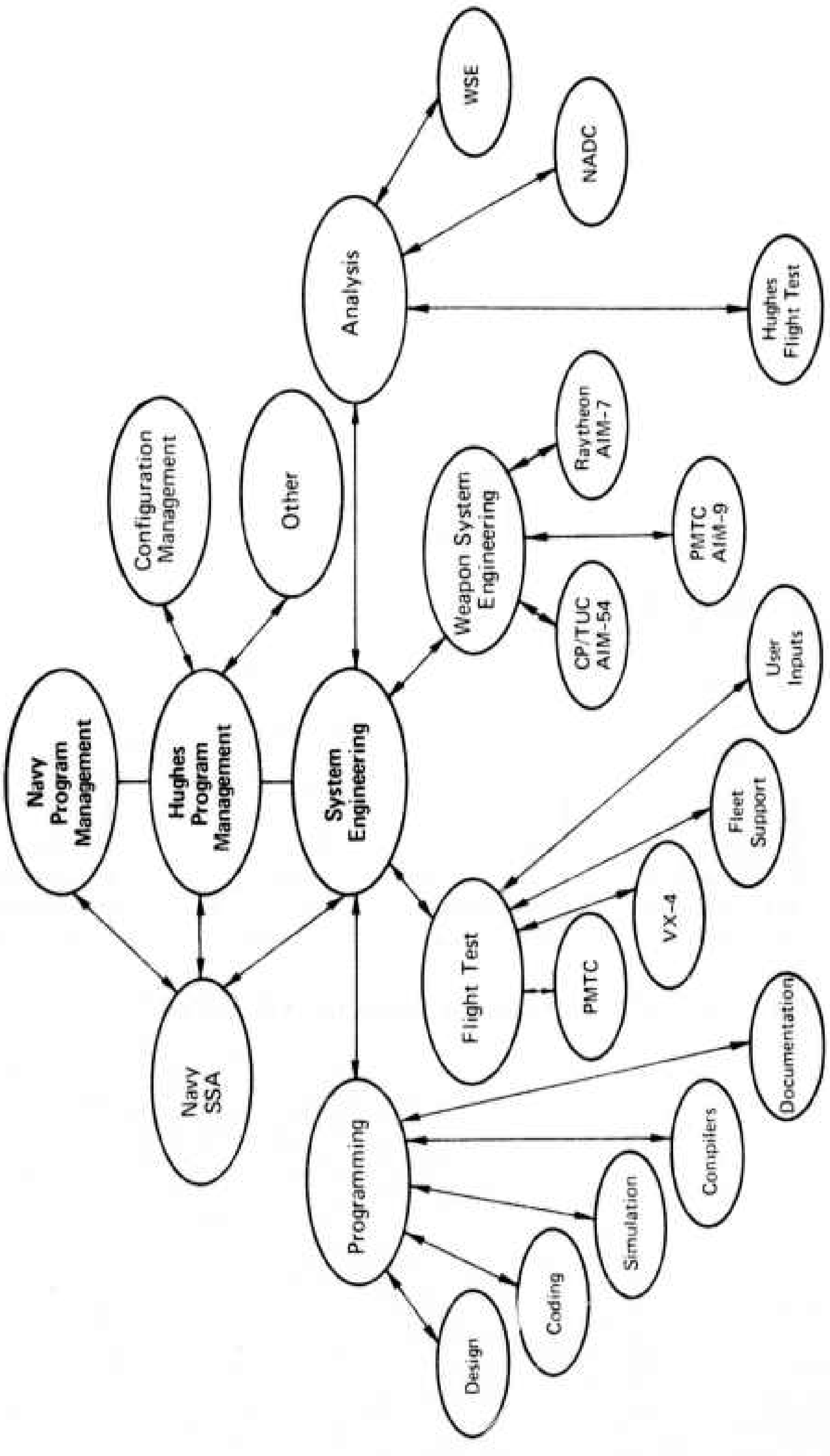


Fig. 5-19 HAC Software Management Organization

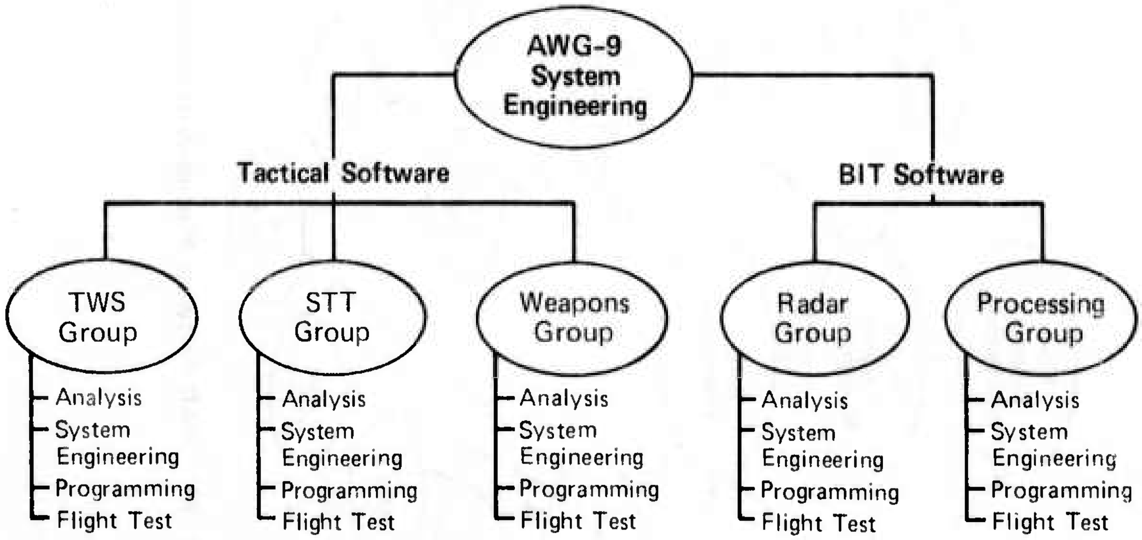


Fig. 5-20 HAC Software Development Staff Groups

paperwork level, and their discovery and resolution are not delayed until the tape is in use in a system laboratory, in flight test, or in actual Fleet deployment. Also, the software system engineering designer and the programmer are available during evaluation, both in the AWG-9 roofhouse and in flight test, to provide the needed insights for quick resolution of system operational problems.

5.6.3 Management Documents

The following documents are relevant to the F-14 software development:

Specifications

- System Specification — F-14A Armament System (AS-2195)
- F-14A Weapon Control System (AS-2197)
- Detailed Specification — AWG-9 Computer Software (AS-2206)
- Interface Specifications — F-14A Weapon Control System Interface with the AIM-7E Guided Missile (AS-2187C)
- F-14A Weapon Control System — Interface with the AIM-9G (AS-2188C)
- F-14A Weapon Control System Interface with the AIM-9G/H (AS-3735)
- F-14A Weapon Control System Interface with F-14A Avionics (AS-2189C)
- F-14A Weapon Control System Installation and Physical Interface with F-14A Aircraft (AS-2191C)
- F-14A Weapon Control System Interface with AIM-7F-4 Guided Missile (AS-2194C)
- AN/AWG-9 (N-3) Interface with the AIM-54-1 Missile (AS-2695)

Miscellaneous

- Master Index, Phoenix F-14A AN/AWG-9 Software (MI 4810CP-100)
- Software Indentured Drawing Lists and Software Design Descriptions (4810CP-7XX)
- Program Listings (4810CP-3XX)
- Agreement of Responsibilities Between Grumman and Hughes (8 Jan 1969)
- Phoenix/F-14A Software Agreement Between Grumman and Hughes (9 Jun 1969)

Phoenix/F-14A Software Configuration Control Agreement Between Hughes and Grumman (13 Oct 1970)

Baseline Software Release Ground Rules by NAVMISCEN/Hughes and Grumman (Tape 111 Ground Rules, 24 Mar 1975)

5.6.4 HAC Management Techniques

The basic contractual requirement for the AWG-9 system was to design to a level of performance. Government-imposed requirements included the F-14 Software Management Plan (NAVAIR PMS 241-VM/SDN SER 75-27 (7 Feb 1975)), and General Purpose, Programmable Airborne Digital Computer Systems Program Data, General Requirements for AR-15 (20 Sept 1967). In addition to Government-imposed requirements, design audit and review are performed through the Navy NTE and NPE and the Navy BIS. AWG-9 computer programs went under MIL-STD-480 product baseline configuration control on 2 May 1975. Test and validation as described in the previous section also served as a management technique.

5.6.5 HAC Management Findings

Hughes strongly believes that the use of a programming subcontractor in software development for avionic systems is counter-productive. They state the position that software development is integral to the system design process, and the system design cannot be developed on paper to the extent that a programmer can develop an acceptable product. Also, coding is a trivial part of the overall job of software development.

5.6.6 GAC Management

Management of the Grumman effort is concentrated at the total system (aircraft) level, software being a rather insignificant part of the whole. No formal management strucure could be identified in connection with the software (CSDC) effort.

5.7 OPERATIONAL SOFTWARE MAINTENANCE

The ultimate responsibility for operational software maintenance of the AWG-9/CSDC programs will be assigned to the Navy SSA as established by NAVAIR through the Software Management Plan. Figure 5-21 is a block diagram showing the Navy organization. The SSA (at PMTS) has recently taken over configuration management of the AWG-9 computer program (an organizational setup is shown in Fig. 5-22) and is developing documentation and compiler support in preparation for assuming maintenance responsibility. It is expected that significant new support for software maintenance will be required because of the highly technical

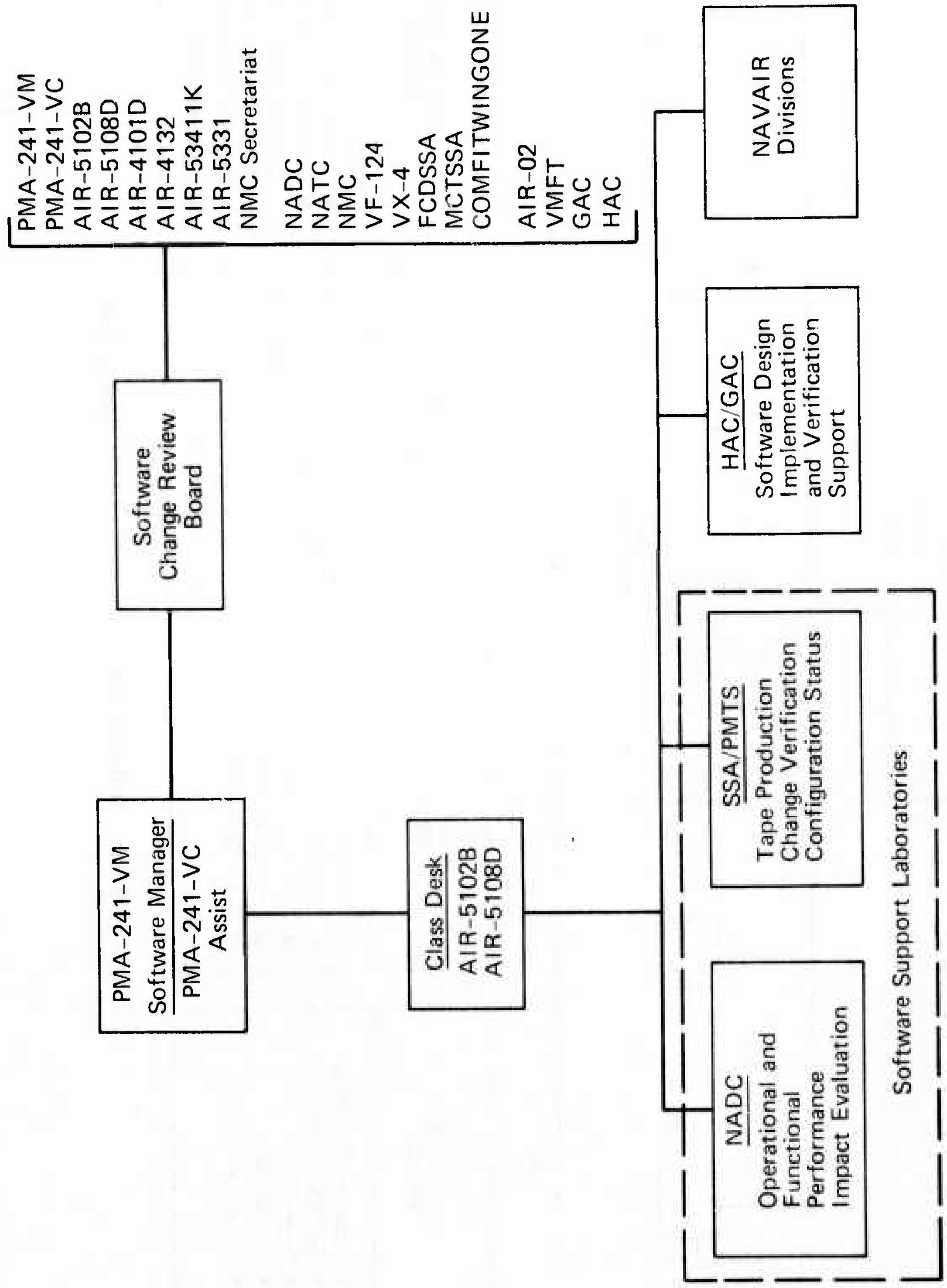


Fig. 5-21 Navy Configuration Management Organization for the F-14

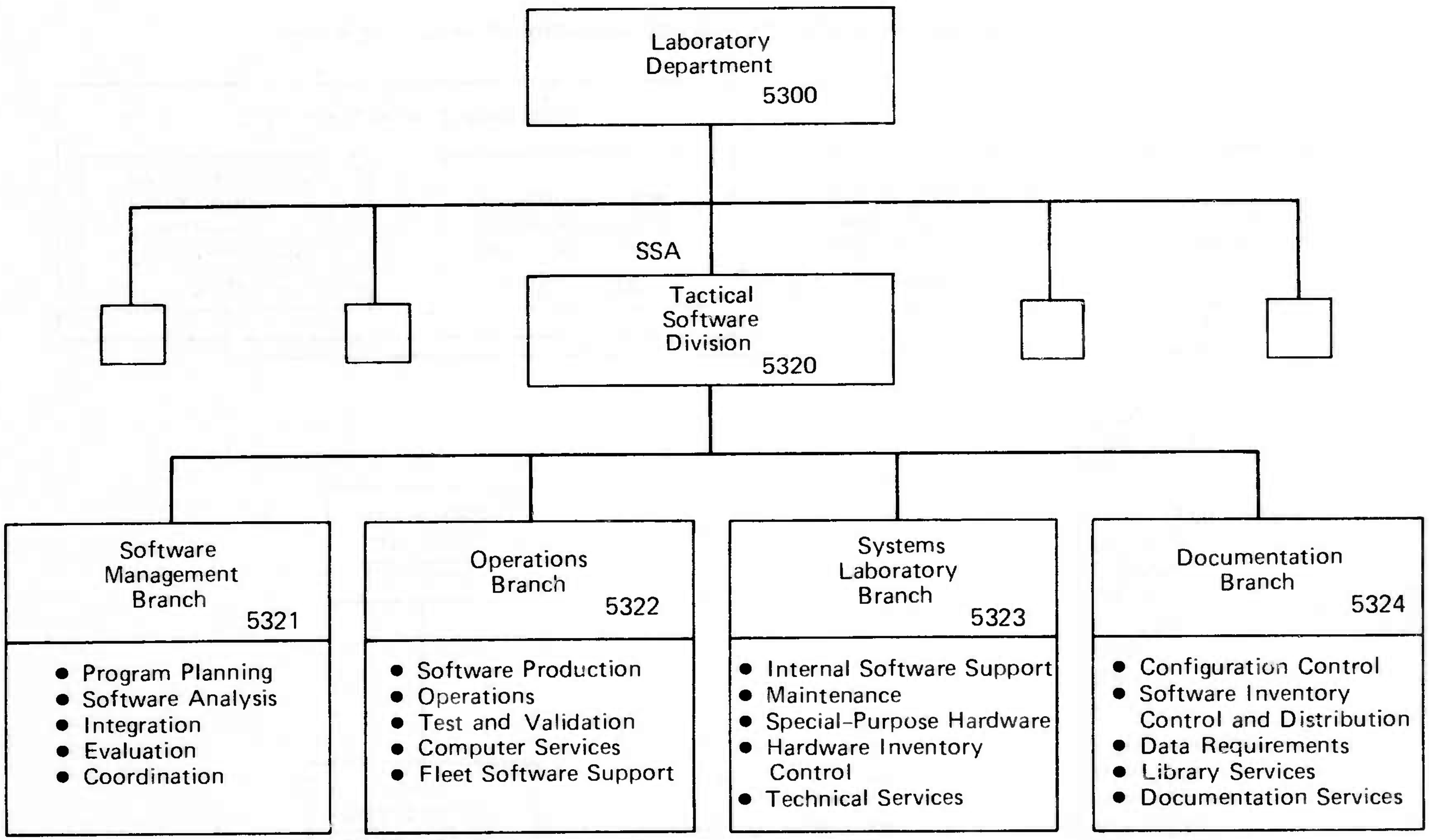


Fig. 5-22 Software Support Activity (SSA) Organization

nature of the computer programs. The functional organization of planned Hughes support to the SSA for all Phoenix programs is shown in Fig. 5-23.

The official procedures to be followed in the software maintenance effort have been documented in a series of memoranda by the SSA.

5.8 HIGHLIGHTS

An AWG-9 design approach based on expanded software interaction and control of system hardware functions permitted a rapid hardware development cylce. The system flexibility provided by the AWG-9 software has permitted AWG-9 system growth and functional improvement without hardware modification to in-service systems. (MP1,SE1,SE2)

Extensive flexibility and growth potential was designed into the AWG-9 computer interface hardware to permit integration of devices with a variety of interface types. A programmable I/O controller and interface capability for parallel, serial, DMA, and analog interfaces provides this capability. (MP1,SE1,SE2)

At the time that the AWG-9 was developed, NDRO memory provided the speed and security required for program instruction storage. However, other protection techniques now available would probably permit use of the more flexible DRO memories for new systems. (SE1)

The Metaplan compiler was developed for the AWG-9 to provide a machine-independent, high-level language with a stringent requirement for efficiency of generated code. Benchmark tests indicate an efficiency level of 90 to 95% has been achieved. (SE3,IP1)

The establishment of the SITS by Grumman permitted extensive testing and validation of the system software prior and during actual flight testing. A great deal of flexibility was thus obtained in the implementation of the system. The location of SITS at a government installation (PMR, Pt. Mugu) enhances the transferability of the system software to the Navy SSA. (IP3)

Validation and integration of computer programs is performed at extensive simulation facilities at the Hughes roofhouse facility (AWG-9) and at the Grumman SITS integration facility (total system level) at PMR. SITS also provided the facility for the first two-way Link 4A tests. (IP3)

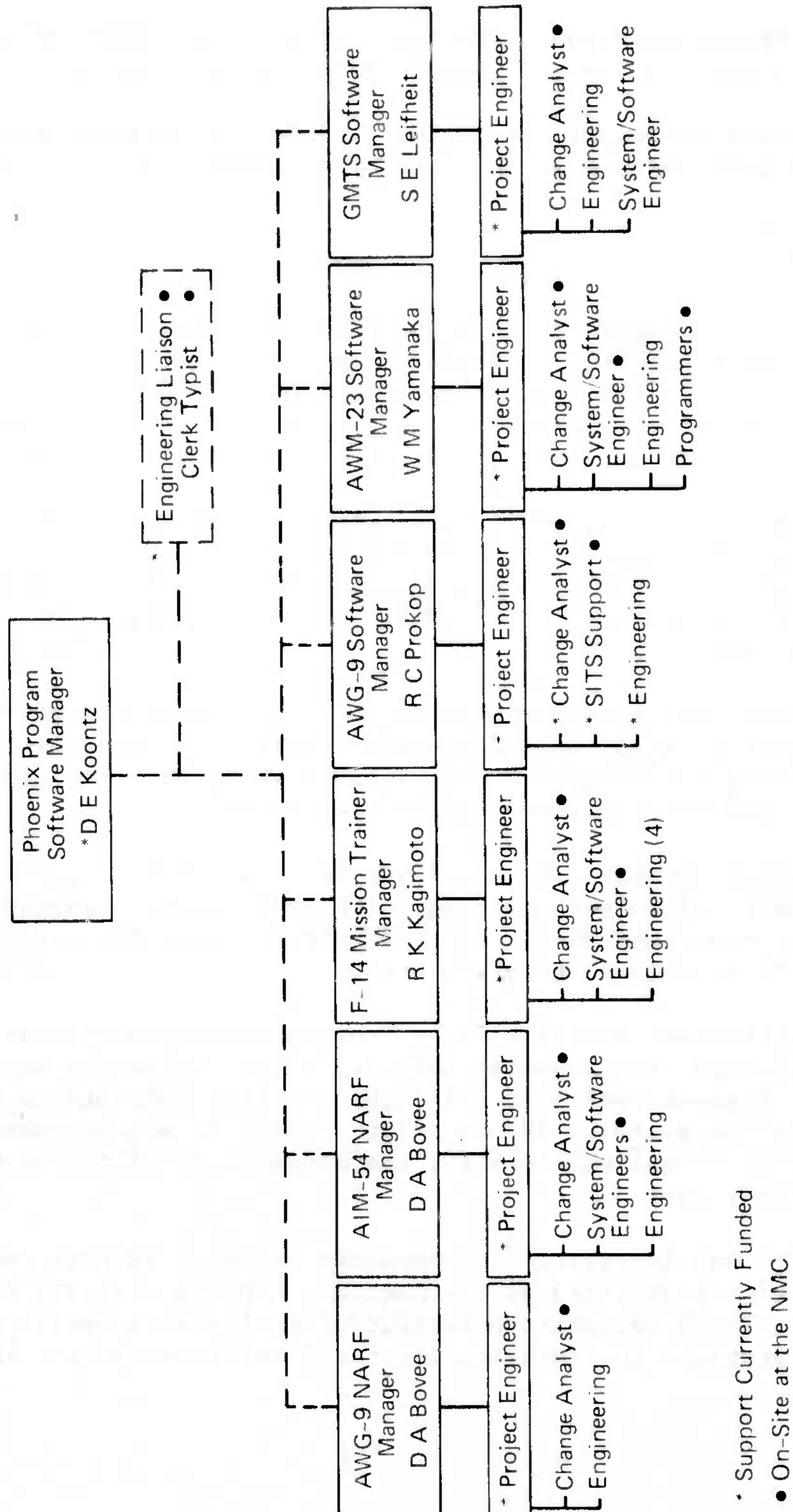


Fig. 5-23 Functional Organization of Hughes SSA Support

INITIAL DISTRIBUTION EXTERNAL TO THE APPLIED PHYSICS LABORATORY*

The work reported in SR 75-3C wae done under Navy Contract N00017-72-C-4401. This work is related to Task ZC-6, which is supported by NAVSEASYSCOM.

ORGANIZATION	LOCATION	ATTENTION	No. of Copies
DEPARTMENT OF DEFENSE			
DoD Software Management Steering Committee	OASD (I&L), Pentagon Room 2A318	B. C. DeRoze	25
Department of the Navy			
NAVAIRSYSCOM	Washington, DC	533	5
		5331	1
		PMA 231A	2
		PMA 241 VM	2
FCDSSA(SD)	San Diego, CA	E-2C	1
NADC	Johnsville, PA	P-3C	1
NMC	Pt. Mugu, CA	F-14	1

Requests for copies of this report from DoD activities and contractors should be directed to DDC, Cameron Station, Alexandria, Virginia 22314 using DDC Form 1 and, if necessary, DDC Form 55.

*Initial distribution of this document within the Applied Physics Laboratory has been made in accordance with a list on file in the APL Technical Publications Group.